

A Study of the
MacRae Celestite Deposit
Cape Breton, Nova Scotia

FINAL REPORT

By

Chromasco, a division of Timminco Limited

March 31, 1987

Chromasco Project No. H4038/RDO#H-18-86

Work on this project was conducted under the auspices of
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Étude
sur le gisement de célestine MacRae
Cap Breton (Nouvelle-Écosse)

RAPPORT FINAL

par

Chromasco, division de Timminco Limited

31 mars 1987

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- Section 5 Report on Phase II of DSS Contract
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Section 1

SECTION 1

INTRODUCTION

1.1 Overview

This report presents a summary of work carried out under the direction of Chromasco, a division of Timminco Limited, to establish the economic viability of a commercial mining, concentrating and conversion operation to produce market grade strontium sulphate and strontium carbonate. The operation would use celestite ore from the MacRae celestite ore deposit located at Lake Enon, Cape Breton, Nova Scotia.

The work was conducted under the auspices of the Federal Department of Energy, Mines and Resources, covered by the Federal Department of Supply and Services Contract 23440-6-9031/01-SQ and was completed within the stipulated amount of \$246,205 and was delivered on time March 31, 1987.

1.2 Background

Chromasco's parent company, Timminco Limited started in the 1930's under the name of Chromium Mining & Smelting Corporation Limited, and has evolved from a producer of a single product, ferrochrome, to a producer and manufacturer of a broad range of products including; ferroalloys, strontium, calcium, magnesium, magnesium extrusions, water and solvent based adhesives, hot melts, epoxies and plastisol adhesives. Timminco Limited now has six production facilities in Canada serving diversified markets in North America, Europe, South America and the Pacific Rim countries.

Chromasco, a division of Timminco Limited, operates two groups; Ferrous and Non-Ferrous. The Ferrous Group comprises the Beauharnois, Quebec ferroalloy smelter. The Non-Ferrous Group comprises the Haley, Ontario, magnesium reduction and extrusion plant, and the Westmeath, Ontario, plant, which produces strontium and calcium metals in various forms and alloys.

Chromasco is the largest producer of strontium metal in the world, and the only one in North America. Strontium metal's principal application is in the aluminum industry to modify aluminum-silicon alloy castings.

The primary raw material for strontium metal is strontium carbonate, which is purchased by Chromasco from a limited number of foreign suppliers. Strontium carbonate is derived from the concentration and conversion of high quality celestite (SrSO₄).

SECTION 1

INTRODUCTION

1.2 Background - cont'd.

It is Chromasco's plan to explore the possibility of securing its own source of celestite for its strontium metals operation, and in November 1985, Timminco was granted a license by the Province of Nova Scotia to carry out exploration work on the MacRae celestite property. In July 1986, Timminco was awarded a contract by the Federal Department of Supply and Services to carry out the work described in this Summary Report. (See Section 3 for the detailed Statement of Work

SECTION 1

INTRODUCTION

1.1 Aperçu

Le présent rapport décrit, dans leurs grandes lignes, les travaux effectués sous la direction de Chromasco, une division de Timminco Limited, en vue de déterminer la rentabilité d'une installation d'extraction minière, de concentration et de conversion destinée à produire du sulfate de strontium et du carbonate de strontium de qualité commerciale. L'usine serait alimentée en minerai de célestine provenant du gisement MacRae se trouvant à Lake Enon, Cap Breton (Nouvelle-Écosse).

Menés à bien sous les auspices d'Énergie, Mines et Ressources Canada, les travaux faisaient l'objet du contrat 23440-6-9031/01-SQ d'Approvisionnement et Services Canada. Ils ont été achevés dans les délais, le 31 mars 1987, selon un montant conforme à la somme prescrite de 246 205 \$.

1.2 Historique

Timminco Limited, société-mère de Chromasco, a été fondée en 1930 sous la raison sociale de Chromium Mining & Smelting Corporation Limited. N'offrant à l'origine qu'un seul produit, le ferrochrome, Timminco s'est transformée depuis en un fabricant de toute une gamme de produits dont les suivants : ferro-alliages, strontium, calcium, magnésium, extrusions de magnésium, adhésifs à base d'eau et de solvants, adhésifs thermofusibles, adhésifs époxydes et plastisol. Aujourd'hui, Timminco Limited compte six usines au Canada, lesquelles desservent des marchés très variés en Amérique du Nord, en Europe, en Amérique latine et en Asie.

Chromasco, une division de Timminco Limited, exploite deux groupes, à savoir le groupe des métaux ferreux et celui des métaux non ferreux. Le premier groupe comprend la fonderie de ferro-alliages à Beauharnois, au Québec. Le groupe des métaux non ferreux regroupe l'usine de réduction et d'extrusion du magnésium à Haley (Ontario) et l'usine de Westmeath, en Ontario, qui produit des métaux strontium et des métaux calcium sous diverses formes et en divers alliages.

Chromasco est le plus important producteur de métal strontium au monde, et le seul en Amérique du Nord. Le métal strontium est surtout utilisé dans la transformation de l'aluminium pour modifier les pièces coulées en alliage d'aluminium et de silicium.

La principale matière brute intervenant dans la réalisation du métal strontium est le carbonate de strontium, que Chromasco se procure auprès d'un nombre limité de fournisseurs étrangers. Le carbonate de strontium s'obtient par concentration conversion de célestine de grande qualité (SrSO₄).

SECTION 1

INTRODUCTION

1.2 Historique (suite)

Chromasco se propose d'étudier la possibilité de se procurer sa propre source de célestine pour les usines de métaux strontium; en novembre 1985, le gouvernement de la Nouvelle-Écosse a accordé à Timminco une licence lui permettant d'effectuer des travaux d'exploration sur le gisement de célestine MacRae. En juillet 1986, Timminco a reçu un contrat du ministère fédéral des Approvisionnements et Services pour mener à bien les travaux décrits dans le présent rapport sommaire. (Pour de plus amples renseignements, voir la description détaillée des travaux à la Section 3.)

Section 2

SECTION 2

SUMMARY

2.1 Executive Summary

Chromasco, a division of Timminco Limited began an investigation in November 1985 of the economic viability of establishing a commercial scale strontium carbonate operation based on the MacRae Celestite Deposit and concluded that investigation March 31, 1987 with the issue of this report and associated studies.

It is Chromasco's intention to review the findings of the study, in order to decide whether or not to invest in a commercial operation based on the MacRae Celestite Deposit. No recommendations or conclusions, by Chromasco, on the commercial viability of an investment associated with the MacRae Deposit, are presented in this study.

The investigation concluded the following:

- Calculated ore reserves based on existing drill log data, are sufficient to support a conversion facility to produce 10,000 tonnes per year of strontium carbonate, with a mine life of 11 years.
- The potential exists to at least triple the ore reserves with further exploration drilling.
- All environmental regulations could be met if a mining, concentrating and conversion operation were established in Nova Scotia.
- The existing concentrator can be refurbished and made operational without major modifications.
- A concentrate of over 92% strontium sulphate with a recovery of 80% can be produced in the modified concentrator.
- The concentrate product exceeds the specifications for certain elements, but can be used as feedstock for the 'Black Ash' conversion process.
- The 'Black Ash' process is the most economical for the production of strontium carbonate.

2.1 Executive Summary - cont'd.

- The estimated capital investment in mine, concentrator and conversion plant is \$24,818,000 Canadian funds based on a Nova Scotia location, but not including proceeds from Senior Government Programs for Financial Assistance.

2.2 Overall Summary

2.2.1 Background

Chromasco commissioned G.W. Felderhof of A.C.A. Howe International Ltd. in April 1985, to submit a report on the known celestite deposits in Canada with emphasis on the MacRae Celestite Property in Cape Breton, Nova Scotia. The results of this study indicated that the MacRae Property not only represented the best opportunity for developing a celestite mine in the shortest time frame, but also that the best exploration potential would be in the region surrounding the property, the Loch Lomond area. Other regions identified to have celestite potential on Cape Breton Island include the West Bay and Grand River areas.

Subsequent to this study, a decision was made by Chromasco to proceed with the acquisition of the Exploration Rights to the MacRae Property.

The Exploration Rights were acquired by the Chromasco Division of Timminco Limited on November 1, 1985, by means of a special license issued by the Nova Scotia Department of Mines and Energy, in response to a tender proposal to develop the property by Chromasco. The property comprises 19 claims totalling 760 acres, and is located in the Loch Lomond region of Cape Breton Island, Nova Scotia.

The nearest population centers, of significance, are Port Hawkesbury, 80 km to the southeast and Sydney, 56 km to the northeast. Access to the property from these towns is via paved highway and well maintained secondary gravel roads. The area surrounding the property is sparsely populated.

The celestite deposit on the MacRae Property was discovered in 1973 by Kaiser Celestite Mining Limited, a subsidiary of Kaiser Aluminum and Chemicals Corp. of Oakland, California, who was mining and concentrating celestite approximately one mile to the south at the time of the discovery. Kaiser commenced mining on the MacRae Property in 1975, however stopped in 1976 when they closed down their operations on the basis of soft markets and a corporate decision to divest. During that period, Kaiser mined approximately 93,000 tons (84,545 tonnes), from Pit No. 4 located on the MacRae Property.

2.2.2 The DSS Contract

In April of 1986, the Federal Department of Supply and Services submitted a request to Chromasco for a proposal to undertake laboratory and pilot plant studies on celestite from the MacRae Deposit, Nova Scotia, plus prepare a Prefeasibility Study on the Economic Viability of a Commercial Mining, Concentration and Conversion Operation.

Chromasco responded on April 30, 1986 with a firm proposal to carry out the work and was subsequently awarded the contract July 2, 1986 for a value of \$246,205. The contract was to be conducted under the auspices of the Department of Energy, Mines and Resources, and comprises four phases of activities, which are:

- Phase I - Summary of all known celestite properties in Canada, and the research and development completed to date with the major emphasis on Lake Enon ores.
- Phase II - Conduct batch test work on concentration and conversion to produce specification strontium sulphate and strontium carbonate to the following specifications:

<u>Sulphate</u>		<u>Carbonate</u>	
SrSO ₄	90% min.	SrCO ₃	99% min.
BaSO ₄	1% max.	BaCO ₃	1% max.
SiO ₂	1% max.	CaCO ₃	0.2% max.
Fe ₂ O ₃	0.4% max.	MgCO ₃	0.2% max.
PbO	Low	Na ₂ CO ₃	0.15% max.
		SO ₂	0.08% max.
		Fe ₂ O ₃	0.01% max.

- Phase III - Pilot plant test work on concentration and conversion to produce specification strontium sulphate and strontium carbonate. (Amended at a later date - see Amendment in Section 3)

- Phase IV - Pre-feasibility study for the commercial operation including mining, concentration and conversion to the specified grades of sulphate and carbonate.

(See Section 3 - Statement of Work Under DSS Contract for further details on Scope of Work.)

2.2.2 The DSS Contract - cont'd.

To ensure satisfactory completion of the work to be undertaken, Chromasco assembled a project team with the requisite skills and expertise. The responsible parties and their mandates are:

<u>Party</u>	<u>Mandate</u>
A.C.A. Howe International Toronto, Ontario	<u>Phase I</u> (Part) - Summary of all known celestite properties in Canada. <u>Phase IV</u> (Part) - Ore Reserve Calculations, Mine Design, Mine Capital and Operating Costs.
J.B. McCrea (Consulting) Ltd. Brampton, Ontario	<u>Phase I</u> (Part) - Summary of Past Research and Development on Celestite Ore.
Lakefield Research Lakefield, Ontario	<u>Phase II</u> and <u>Phase III</u>
Phillips Barratt Kaiser Engineering Ltd. Burlington, Ontario Vancouver, B.C.	<u>Phase IV</u> (Part) - Flowsheets for Concentration and Conversion Plants, Capital and Operating Costs, Tailings Disposal, Startup Costs and Economics.

2.2.3 Phase I

Prior to commencing production on the MacRae Property, Kaiser undertook 14,935 feet of diamond drilling in 90 holes, which delineated 4 zones of celestite mineralization; Zones 1, 2, 3 and 4 - stacked like a layer cake with Zone 4 on top, and all dipping 17 deg. to 20 deg. northwest. Zones 1 and 4 are too small to be of consequence, however Zones 2 and 3 are of economic proportions with respect to size and grade. Zone 2 was partially exploited by Kaiser and Zone 3 remains completely intact. Based on the diamond drilling program, Kaiser calculated celestite reserves in these two zones, which were categorized as "measured" and "indicated".

Utilizing the Kaiser data, A.C.A. Howe International Ltd. calculated the following undiluted reserves, which compare closely with the Kaiser reserves.

2.2.3 Phase I - cont'd.

(1) Zone 2

(a) Measured - Pit No. 4 - 67,298 tonnes @ 48.69% SrS04

(b) Measured - North of
Pit No. 4 - 204,351 tonnes @ 49.05% SrS04

TOTAL = 271,649 tonnes @ 48.96% SrS04

(c) Indicated - North of
Measured Reserves - 112,662 tonnes @ 52.72% SrS04

TOTAL = Measured Reserves + Indicated Reserves

= 384,311 tonnes @ 50.19% SrS04

(2) Zone 3

(a) Measured - North of
Pit No. 4 - 185,998 tonnes @ 61.49% SrS04

(b) Indicated - North of
Measured Reserves - 72,082 tonnes @ 54.31% SrS04

TOTAL = Measured Reserves + Indicated Reserves

= 258,080 tonnes @ 59.48% SrS04

(3) GRAND TOTALS - ZONE 2 + ZONE 3

Measured - 457,647 tonnes grading 54.05% SrS04

Indicated - 184,744 tonnes grading 53.34% SrS04

TOTAL = 642,391 tonnes grading 53.84% SrS04

The measured reserves are at depths between 31 and 204 feet below surface, and the indicated reserves between 163 and approximately 315 feet below surface.

2.2.3 Phase I - cont'd.

It is anticipated that at least the measured reserves (457,647 tonnes @ 54% SrS04) will be extracted by open pit mining, however the ultimate pit depth will be determined by the waste to ore stripping ratio and the ore cut-off grade. At current prices for SrS04, and current mining and milling cost estimates, a cut-off grade of 30% SrS04 over 5 feet appears reasonable and is used in the reserve calculations.

(See Section 4, for further information.)

2.2.4 Phase II

The results of the metallurgical test work completed by Lakefield Research in Phase II were successful, in that a high grade SrS04 concentrate and SrC03 could be produced from the MacRae ore, however problem areas were identified which had to be addressed at a Review Meeting (Clause 2.2.5).

The SrS04 concentrate can be economically produced, however it does not meet the specifications with respect to BaS04 - maximum 1%, and Pb - preferably nil. Neither of these contaminants can be removed in the concentration - beneficiation process. Lakefield Research was successful in removing these in the conversion process. An analysis of the operating costs of the Lakefield conversion process on a production scale show that it would be too expensive to be considered as a potential process. In addition, there are some problems with this process meeting the specifications with respect to Na and Ca, although Lakefield is confident that this can be corrected. (See Section 5 for details of Phase II Testwork)

2.2.5 Phase I and II Review Meeting

At the completion of Phases I and II, a meeting was arranged on December 4 and 5, 1986 to review project progress, particularly the results of the metallurgical test work, and to identify requirements to be fulfilled in the pre-feasibility study. Representatives of all parties involved in the project were present.

As a consequence of the unacceptably high production cost associated with the Lakefield Research Conversion process, two alternate processes were discussed at length at the Dec. 4 and 5 meeting, and it was decided that these be more fully investigated to ascertain if they should be included in further work under the DSS Contract.

2.2.5 Phase I and Phase II Review Meeting - cont'd.

One of these processes is the "Kaiser Process", which essentially is crude conversion (metathesis), calcination and carbonation. The other is the "Black Ash Process", which essentially is calcination, leaching and carbonation.

The Kaiser Process produces high grade SrCO_3 , however additional research and development is required with respect to the process and calciner equipment. This process is also sensitive to energy prices.

The Black Ash Process also produces high grade SrCO_3 , however the potential by-products of H_2S and Na_2S could present a costly environmental control problem, unless a lower cost process to eliminate them can be developed. Both processes are addressed in the pre-feasibility study carried out by PBK. (See Section 7)

Subsequent to the Dec. 4 and 5 meeting, the Statement of Work under the DSS Contract was amended to delete the conversion pilot plant work for Phase III. The funds for the conversion pilot work were transferred to Phase IV - Prefeasibility Study. (See Section 3 for the Amendment to the Statement of Work under DSS Contract) Phillips Barrett Kaiser Engineering Ltd. and their associate Kaiser Engineers, Inc. have sufficient in house data to complete most of the study with a high degree of confidence without pilot scale work being necessary on the 'Black Ash' or 'Kaiser Process'.

2.2.6 Phase III

Lakefield completed Phase III Pilot Scale Concentration Work and presented their findings in a report dated March 25, 1987. (See Section 6). The tests produced celestite concentrates assaying 90 to 92% SrSO_4 at greater than 80% recovery of the celestite in the feed. Recovery fell off sharply in celestite concentrates grading 92% SrSO_4 and greater. The analysis of the 92% grade concentrate is compared to specification below:

	<u>Pilot Plant Product</u>	<u>Specification</u>
	SrSO_4	92%
*	BaSO_4	90% min.
	CaCO_3	1%
	MgCO_3	
	Fe_2O_3	0.4%
	Al_2O_3	
	SiO_2	1%
+	Pb	Low
		0.17%

* 1.5% is acceptable with the 'Black Ash' conversion process.

+ A high lead value could pose an environmental hazard if conversion plant does not have suitably designed tailings impoundment. A new plant in N.S. could accept this high lead.

2.2.6 Phase III - cont'd.

Although the BaSO₄ exceeds the specification value, 1.5% BaSO₄ is acceptable provided that it is consistent, according to a major carbonate producer utilizing the Black Ash Process.

In the conversion process, the lead values report to the sludge in a more concentrated form and therefore can pose a threat to the environment. It does not appear that the high lead value will be a problem where proper impoundment facilities are provided.

2.2.7 Phase IV

Data used by PBK for the concentrator design was based on Phase III Pilot Scale Work.

The Prefeasibility Study by PBK considered the following cases for the conversion plant:

- Case 1A - White Ash Process as practiced by Kaiser Aluminum and Chemical Corporation at the original facility at Point Edward.
- Case 1B - White Ash Process as Case 1A except utilizing locally available salt to produce the required reagents.
- Case 2 - Black Ash Process as practiced by the current producers of strontium carbonate.

Based on the capital and operating costs developed during the study, the Black Ash is the most economical, while both the White Ash Processes appear to be marginal.

Conclusions established by the Phase IV Study are:

- Calculated ore reserves based on existing data are sufficient to support a conversion facility to produce 10,000 tonnes per year of strontium carbonate with a mine life of 11 years.
- The potential exists to at least triple the ore reserves with further exploration drilling.
- All environmental regulations can be met.
- The existing concentrator can be refurbished and made operational without major modifications.
- The 'Black Ash' process is the most economical for the production of strontium carbonate.

See Section 7 for further elaboration on the Prefeasibility Study by PBK.

2.2.7 Phase IV - cont'd

The results of this study indicate that the project could be viable and if the decision is made to develop it further, the following events would take place.

- Evaluation of the pre-feasibility study.
- Marketing study, in-fill drilling, and decision to proceed with a detailed feasibility study on the selected process.
- Conduct sampling, laboratory and pilot plant work and equipment testing.
- Prepare environmental permits.
- Prepare feasibility study.
- Arrange financing.
- Decision to proceed with engineering and construction.

An overall schedule is dependent on many things but a suggested sequence of milestone dates could be as follows:

Pre-feasibility study complete	- April 15/87
Marketing study start	- May 1/87
In-fill drilling start	- June 1/87
Decision to proceed with feasibility study	- Sept. 1/87
Pilot work, equipment tests and feasibility study complete	- Dec. 1/87
Study review, financing and partnership discussions and decision to proceed	- July 1/88
Environmental permitting, purchase of concentrator and start engineering	- Nov. 1/88
Construction start	- April 1/89
Start-up	- March 1/90

2.2.7 - Phase IV - cont'd

To complete a feasibility study, additional drilling is required to confirm the existing Kaiser data and to define more ore reserves. A more detailed study would be completed on the mine plan in an attempt to reduce the cost of mining for such a relatively low tonnage. Sampling for metallurgical and process testwork would be based on the additional data to ensure a closer match as possible to the final plant feed.

The environmental permitting process would start with the base line evaluation upon the decision to proceed with the study. This would continue throughout the study and the remainder of the project schedule till these and the other permits were obtained. It would be expected that the financing would continue in a like manner.

SECTION 2

SOMMAIRE

2.1 Condensé

Chromasco, une division de Timminco Limited, a entrepris, en novembre 1985, une enquête visant à établir s'il serait rentable de mettre sur pied une usine fabriquant, à une échelle industrielle, du carbonate de strontium à partir du minerai de célestine extrait du gisement MacRae. L'enquête a pris fin le 31 mars 1987 avec la parution du présent rapport et d'études connexes.

Chromasco a l'intention de se pencher sur les conclusions de l'étude afin de décider s'il y a lieu ou non de consentir les investissements nécessaires à la création d'une usine pour mettre en valeur le gisement de célestine MacRae. Aucune recommandation ni conclusion formulée par Chromasco sur la rentabilité d'un tel investissement n'est présentée dans le cadre de cette étude.

Les conclusions de l'enquête étaient les suivantes :

- Les réserves de minerai, calculées selon les données de sondage existantes, sont suffisantes pour occuper une usine de conversion pouvant débiter 10 000 tonnes par année de carbonate de strontium; la durée de vie de la mine serait alors de 11 ans.
- De nouveaux sondages d'exploration permettraient éventuellement de tripler le chiffre des réserves de minerai.
- Il serait possible de mettre sur pied, en Nouvelle-Écosse, une usine d'extraction minière, de concentration et de conversion, tout en respectant les normes de protection de l'environnement.
- Le concentrateur actuel, moyennant de légères modifications, peut être remis en état de marche.
- Ainsi modifié, le concentrateur peut produire un concentré à plus de 92 % de sulfate de strontium avec un taux de récupération de l'ordre de 80 %.
- La teneur du concentré en certains éléments dépasse les richesses limites prévues, mais le concentré peut servir de charge d'alimentation pour le procédé de conversion à cendre noire.
- Le procédé à cendre noire est le plus économique pour produire le carbonate de strontium.

2.1 Condensé (suite)

- L'établissement d'une mine, d'un concentrateur et d'une usine de conversion à l'endroit précité en Nouvelle-Écosse exigera un investissement en capitaux d'environ 24 425 000 \$ CAN, montant estimatif qui ne tient toutefois pas compte des crédits pouvant être obtenus dans le cadre des programmes d'aide financière accordé par le gouvernement.

2.2 Sommaire

2.2.1 Historique

En avril 1985, G.W. Felderhof, de la société A.C.A. Howe International Ltd., a été retenu par Chromasco pour préparer un rapport sur tous les gisements connus de célestine au Canada, et notamment sur le gisement MacRae à Cap Breton (Nouvelle-Écosse). Ce recensement a permis de conclure que non seulement la propriété MacRae était le gisement de célestine le plus propice à l'établissement d'une mine dans les plus brefs délais, mais aussi qu'elle se trouvait dans une région, celle du Loch Lomond, qui offrait le meilleur potentiel sur le plan de l'exploration. D'autres régions offrant un certain intérêt pour l'extraction de la célestine sur l'île du Cap Breton sont les régions de West Bay et de Grand River.

Par suite de ce recensement, Chromasco a décidé de prendre les mesures nécessaires pour obtenir les droits d'exploration de la propriété MacRae.

Ces droits d'exploration ont été acquis par la division Chromasco de Timminco Limited le 1er novembre 1985, grâce à la délivrance d'une licence spéciale par le ministère des Mines et de l'Énergie de la Nouvelle-Écosse. Le Ministère provincial faisait suite à une proposition de Chromasco, formulée dans le cadre d'un appel d'offres, pour la mise en valeur de la propriété. Celle-ci est constituée de 19 concessions représentant au total 760 acres et se trouve dans la région Loch Lomond de l'île du Cap Breton, en Nouvelle-Écosse.

Les centres urbains les plus proches sont Port Hawkesbury, à 80 km au sud-est et Sydney, à 56 km au nord-est. L'accès de la propriété depuis ces villes est ménagé par une route asphaltée et par des routes secondaires en gravier bien entretenues. La propriété se trouve dans une région peu peuplée.

Le gisement de célestine de la propriété MacRae a été découvert en 1973 par Kaiser Celestite Mining Limited, une filiale de Kaiser Aluminum and Chemicals Corp. d'Oakland (Californie) qui, au moment de la découverte, assurait l'extraction et la concentration de la célestine à un mille environ au sud du gisement. Kaiser entama la mise en valeur du gisement MacRae en 1975, mais mit fin aux opérations en 1976 lorsque la filiale canadienne ferma ses portes en raison du fléchissement des marchés et de la décision, prise par la maison-mère, de désinvestir. Durant cette période, Kaiser avait extrait environ 93 000 tonnes (84 545 tonnes métriques) de la mine n° 4 située sur la propriété MacRae.

2.2.2 Le contrat du MAS

En avril 1986, le ministère fédéral des Approvisionnements et Services a demandé à Chromasco de lui soumettre une proposition concernant l'étude, en laboratoire et en usine-pilote, de la célestine extraite du gisement MacRae (Nouvelle-Écosse) et de préparer une étude de faisabilité préliminaire sur la rentabilité éventuelle d'une usine d'extraction minière, de concentration et de conversion.

En réponse à cette demande, Chromasco s'est engagé à effectuer le travail dans une proposition ferme soumise le 30 avril 1986, ce qui a valu à la compagnie d'obtenir, le 2 juillet 1986, un contrat d'une valeur de 246 205 dollars. L'exécution du contrat se déroulerait sous les auspices du ministère de l'Énergie, des Mines et des Ressources et comporterait quatre phases, à savoir :

Phase I - Recensement de tous les gisements connus de célestine au Canada et sommaire des travaux de recherche et de développement terminés jusqu'à cette date, notamment en ce qui concerne les minerais de Lake Enon.

Phase II - Essais en laboratoire sur les procédés de concentration et de conversion susceptibles de produire du sulfate de strontium et du carbonate de strontium répondant aux spécifications suivantes :

<u>Sulfate</u>		<u>Carbonate</u>	
SrSO ₄	90 % min.	SrCO ₃	99 % min.
BaSO ₄	1 % max.	BaCO ₃	1 % max.
SiO ₂	1 % max.	CaCO ₃	0,2 % max.
Fe ₂ O ₃	0,4 % max.	MgCO ₃	0,2 % max.
PbO	Low	Na ₂ CO ₃	0,15 % max.
		SO ₂	0,08 % max.
		Fe ₂ O ₃	0,01 % max.

Phase III - Travaux en usine-pilote sur les procédés de concentration et de conversion susceptibles de produire du sulfate de strontium et du carbonate de strontium répondant aux spécifications. (modifié par la suite - voir le modificatif Section 3.)

Phase IV - Étude de faisabilité préliminaire sur la création d'une entreprise commerciale ayant pour activité l'extraction du minerai, sa concentration et sa conversion en sulfate et en carbonate de qualité prescrite.

(Pour de plus amples détails sur la portée des travaux, voir la Section 3 - Description des travaux prévus en vertu du contrat MAS.)

2.2.2 Le contrat du MAS (suite)

Afin de garantir que les travaux soient effectués de façon satisfaisante, Chromasco a mis sur pied une équipe de projet réunissant toutes les compétences et les connaissances nécessaires. Voici les parties retenues et leurs mandats respectifs :

<u>Partie</u>	<u>Mandat</u>
A.C.A. Howe International Toronto (Ontario)	<u>Phase I</u> (en partie) - Recensement sommaire de tous les gisements connus de cêlestine au Canada. <u>Phase IV</u> (en partie) - Calcul des réserves de minerai, conception des mines, calcul des coûts d'investissement et des frais d'exploitation de la mine.
J.B. McCrea (Consulting) Ltd. Brampton (Ontario)	<u>Phase I</u> (en partie) - Historique des travaux de recherche et de développement effectués jusqu'à présent sur le minerai de cêlestine.
Lakefield Research Lakefield (Ontario)	<u>Phase II</u> et <u>Phase III</u>
Phillips Barratt Kaiser Engineering Ltd. Burlington (Ontario) Vancouver (C.-B.)	<u>Phase IV</u> (en partie) - Organigrammes pour les usines de concentration et de conversion, calcul des coûts d'investissement et d'exploitation, élimination des résidus, coûts de démarrage et aspects économiques.

2.2.3 Phase I

Avant d'entamer la production sur la propriété MacRae, Kaiser a pratiqué 90 trous de sonde par forage au diamant, sur une profondeur totale de 14 935 pieds. Cette opération a permis de délimiter quatre zones de cêlestine, à savoir les zones 1, 2, 3 et 4, superposées de haut en bas en commençant par la zone 4, qui accusaient toutes une inclinaison de 17° à 20° en vers le nord-ouest. Les zones 1 et 4, trop petites, ne sont pas dignes d'intérêt, mais les zones 2 et 3 tant par leur taille que par la qualité du minerais sont exploitables à une échelle industrielle. La zone 2 avait été partiellement exploitée par Kaiser, tandis que la zone 3 demeure vierge. Par suite de ses opérations de forage au diamant, Kaiser a calculé les réserves de cêlestine dans les zones 2 et 3 suivant deux catégories, soit les réserves "mesurées" et les réserves "indiquées".

À l'aide des données fournies par Kaiser, A.C.A. Howe International Ltd. a calculé que les réserves non diluées correspondent aux chiffres suivants, qui se rapprochent sensiblement des résultats obtenus par Kaiser.

2.2.3 Phase I (suite)

1) Zone 2

a) Mesurées - Mine n° 4 - 67 298 tonnes @ 48,69 % SrSO₄

b) Mesurées - Au nord de la
mine n° 4 - 204 351 tonnes @ 49,05 % SrSO₄

TOTAL = 271 649 tonnes @ 48,96 % SrSO₄

c) Indiquées - Au nord des réserves
mesurées - 112 662 tonnes @ 52,72 % SrSO₄

TOTAL = Réserves mesurées + réserves indiquées
= 384 311 tonnes @ 50,19 % SrSO₄

2) Zone 3

a) Mesurées - Au nord de la
mine n° 4 - 185 998 tonnes @ 61,49 % SrSO₄

b) Indiquées - Au nord des réserves
mesurées - 72 082 tonnes @ 54,31 % SrSO₄

TOTAL = Réserves mesurées + réserves indiquées
= 258 080 tonnes @ 59,48 % SrSO₄

3) TOTAL GÉNÉRAL - ZONE 2 + ZONE 3

Mesurées - 457 647 tonnes à 54,05 % de teneur en SrSO₄

Indiquées - 184 744 tonnes à 53,34 % de teneur en SrSO₄

TOTAL = 642 391 tonnes à 53,84 % de teneur en SrSO₄

Les réserves mesurées se trouvent à des profondeurs comprises entre 31 pieds et 204 sous le niveau du sol, tandis que les réserves indiquées sont comprises entre 163 et environ 315 pieds sous ce même niveau.

2.2.3 Phase I (suite)

On prévoit que les réserves mesurées (457 647 tonnes @ 54 % SrSO_4), sinon les réserves indiquées, seront extraites à ciel ouvert, bien que la profondeur finale des excavations sera conditionnée par le rapport du stérile au minerai et par la richesse limite inférieure de ce dernier. Compte tenu du prix actuel du SrSO_4 et compte tenu des frais estimatifs d'extraction et de broyage, une teneur limite inférieure de 30 % en SrSO_4 sur 5 pieds de profondeur semble raisonnable et a été retenue pour les calculs sur les réserves. (Pour de plus amples renseignements, voir la Section 4.)

2.2.4 Phase II

Les travaux d'essai en métallurgie effectués par Lakefield Research dans le cadre de la Phase II ont donné des résultats probants, puisqu'il est possible de produire un concentré de SrSO_4 et du carbonate de strontium de haute qualité à partir du minerai MacRae. Toutefois, on a cerné certaines difficultés dont il a fallu discuter dans le cadre d'une réunion de mise au point (Paragraphe 2.2.5).

Le concentré de SrSO_4 peut être produit de façon rentable, mais ne respecte pas les spécifications pour ce qui est de la teneur en BaSO_4 (1 % au maximum) et au Pb (nulle de préférence). Or, ni l'un ni l'autre de ces contaminants ne peut être éliminé durant le procédé de concentration et d'enrichissement. Lakefield Research a réussi à les retirer durant le procédé de conversion. Mais, par suite d'une analyse des frais d'exploitation que supposerait le procédé de conversion Lakefield à une échelle industrielle, force a été de conclure que ce procédé serait trop onéreux. Avec ce procédé, il est en outre difficile de se conformer aux spécifications portant sur la teneur en Na et en Ca, bien que Lakefield ne doute pas de pouvoir corriger le problème. (Pour une description détaillée des essais effectués durant la Phase II, voir la Section 5.)

2.2.5 Réunion sur les phases I et II

Une fois terminées les phases I et II, une réunion a été tenue les 4 et 5 décembre 1986 pour faire un premier bilan de l'avancement du projet, et notamment pour étudier les résultats des travaux d'essai en métallurgie et de cerner les conditions à remplir dans l'étude préliminaire de faisabilité. Ont assisté à cette réunion des représentants de toutes les parties collaborant au projet.

Étant donné que le procédé de conversion Lakefield Research aurait entraîné des coûts de production beaucoup trop élevés on a longuement discuté de deux procédés de rechange lors de la réunion des 4 et 5 décembre, et l'on a décidé que ces procédés feraient l'objet d'une enquête plus poussée afin de savoir s'il y aurait lieu ou non de les placer sous le coup du contrat MAS.

2.2.5 Réunion sur les phases I et II (suite)

L'un de ces procédés est le "procédé Kaiser", qui consiste pour l'essentiel en la conversion (métathèse), la calcination et la carbonation du minerai. L'autre procédé, à cendre noire, consiste pour l'essentiel en la calcination, la lixiviation et la carbonation du minerai.

Le procédé Kaiser donne un carbonate de strontium de haute qualité, mais devra faire l'objet de travaux de recherche et de développement plus poussés, tout comme le matériel de calcination. Par ailleurs, le coût de ce procédé est sensible aux prix de l'énergie.

Le procédé à cendre noire permet également d'obtenir un carbonate de strontium de haute qualité, mais risque de donner lieu à deux dérivés, le H₂S et Na₂S. Ces produits pourraient poser un problème de pollution qu'il serait coûteux de contrôler, à moins que l'on puisse mettre au point un procédé d'élimination moins onéreux. Il est question de ces deux procédés dans l'étude de faisabilité préliminaire effectuée par PBK. (Voir la section 7.)

Par suite de la réunion des 4 et 5 décembre, on a modifié la Description des travaux du contrat MAS de façon à supprimer une partie de la Phase III, à savoir les travaux en usine-pilote sur la conversion. Les montants réservés pour ces derniers travaux ont été réaffectés à la Phase IV, à savoir l'étude de faisabilité préliminaire. (Le modificatif apporté à la Description des travaux du contrat MAS figure à la Section 3.) La Société Phillips Barrett Kaiser Engineering Ltd. et la firme associée Kaiser Engineers, Inc. possèdent suffisamment de données en dossier pour mener cette étude à bien sans devoir recourir à des travaux en usine-pilote sur le procédé à cendre noire ou sur le procédé Kaiser.

2.2.6 Phase III

Après avoir achevé les travaux en usine-pilote sur la concentration du minerai, prévus à la Phase III, Lakefield a présenté ses conclusions dans un rapport en date du 25 mars 1987. (Voir la Section 6.) Les essais ont produit des concentrés de célestine offrant une teneur de 90 % à 92 % en SrSO₄, avec un taux de récupération de plus de 80 % de la célestine dans la charge d'alimentation. Ce taux de récupération diminue de façon marquée dans le cas des concentrés de célestine ayant une teneur en SrSO₄ de 92 % ou plus. L'analyse du concentré à 92 % est comparée aux spécifications dans le tableau ci-dessous :

	Produit d'usine-pilote	Spécification
SrSO ₄	92 %	90 % min.
* BaSO ₄	1,48 %	1 %
CaCO ₃	3,18 %	
MgCO ₃	1,23 %	
Fe ₂ O ₃	0,13 %	0,4 %
Al ₂ O ₃	0,13 %	
SiO ₂	0,54 %	1 %
+ Pb	0,17 %	Faible

* Pour le procédé de conversion à cendre noire, 1,5 % est une teneur acceptable.

+ Une forte teneur en plomb risquerait de poser un danger pour l'environnement si l'usine de conversion n'est pas équipée d'installations convenables pour la rétention des résidus. Une nouvelle usine en Nouvelle-Écosse serait en mesure de traiter cette forte concentration de plomb.

2.2.6 Phase III (suite)

Bien que la teneur du concentré en BaSO_4 dépasse la teneur prescrite, soit 1,5 %, cette teneur est acceptable à condition qu'elle soit uniforme. C'est ce qu'affirme un important producteur de carbonate dont les usines font appel au procédé à la cendre noire.

Durant le procédé de conversion, le plomb se retrouve dans les déchets sous une forme plus concentrée et pose un certain danger pour l'environnement. Dans la mesure où l'usine possède des installations convenables de rétention, il ne semble pas que cette concentration de plomb posera un problème.

2.2.7 Phase IV

Les données employées par PBK pour la conception du concentrateur provenaient des travaux effectués en usine-pilote à la Phase III.

Dans son étude de faisabilité préliminaire, PBK a analysé les formules suivantes pour l'usine de conversion :

Cas 1A - Procédé à cendre blanche, tel qu'employé par la Kaiser Aluminum and Chemical Corporation dans l'usine d'origine à Point Edward.

Cas 1B - Procédé à cendre blanche, comme dans le cas 1A, si ce n'est que les réactifs seront produits avec du sel obtenu sur place.

Cas 2 - Procédé à cendre noire tel qu'employé par les producteurs actuels de carbonate de strontium.

D'après les dépenses en capital et les frais d'exploitation prévus dans l'étude, le procédé à cendre noire est le plus rentable, tandis que les deux procédés à cendre blanche semblent être marginaux.

L'étude de faisabilité préliminaire, soit la Phase IV du projet, offre les conclusions suivantes :

- Les réserves de minerai, calculées selon les données de sondage existantes, sont suffisantes pour occuper une usine de conversion pouvant débiter 10 000 tonnes par année de carbonate de strontium; la durée de vie de la mine serait alors de 11 ans.

- D'après le potentiel constaté, on pourrait au moins tripler le chiffre des réserves de minerai.

- Les normes de protection de l'environnement peuvent être respectées.

- Le concentrateur actuel, moyennant de légères modifications, peut être remis en état de marche.

- Le procédé à cendre noire est le plus économique pour produire le carbonate de strontium.

Voir la section 7 pour de plus amples détails sur l'étude de faisabilité préliminaire effectuée par PBK.

2.2.7 Phase IV (Suite)

Les résultats de cette étude attestent de la viabilité de ce projet et si on décidait de le pousser plus loin, il faudrait envisager les étapes suivantes pour le mener à bien:

- Évaluation de l'étude préliminaire de faisabilité.
- Étude de mise en marché, sondage complémentaire et décision d'entreprendre une étude de faisabilité détaillée du procédé sélectionné.
- Procéder aux travaux d'échantillonnage, de laboratoire et en usine-pilote et à l'essai des équipements.
- Préparer les permis relatifs à l'environnement.
- Préparer l'étude de faisabilité.
- Financer le projet.
- Prendre la décision de commencer les travaux de génie et de construction.

L'échéancier général dépend d'un nombre de facteurs, mais il pourrait tenir compte des principales étapes suggérées ci-après:

- | | |
|---|--------------------|
| - Fin de l'étude préliminaire de faisabilité | 15 avril 1987 |
| - Début de l'étude de mise en marché | 1er mai 1987 |
| - Début du sondage complémentaire | 1er juin 1987 |
| - Décision d'entreprendre l'étude de faisabilité | 1er septembre 1987 |
| - Travaux pilotes, essais des équipements et fin de l'étude de faisabilité | 1er décembre 1987 |
| - Examen de l'étude, discussions quant au financement et aux partenaires et décision d'aller de l'avant | 1er juillet 1988 |
| - Délivrance des permis du Ministère de l'Environnement, achat d'un concentrateur et début des travaux d'ingénierie | 1er novembre 1988 |
| - Début de la construction | 1er avril 1989 |
| - Démarrage | 1er mars 1990 |

2.2.7 Phase IV (Suite)

Afin de terminer l'étude de faisabilité, des travaux de sondage complémentaires sont nécessaires dans le but de confirmer les données actuelles de Kaiser et d'établir les réserves additionnelles de minerai. Une étude plus détaillée pourrait être menée sur le plan de la mine en vue de réduire les coûts miniers à cause du tonnage relativement faible auquel nous avons affaire. Les travaux d'essai en métallurgie et des procédés seraient entrepris d'après les données complémentaires afin d'obtenir des résultats les plus proches des charges d'alimentation définitives de l'usine.

Le processus de délivrance des permis relatifs à l'environnement pourrait être entamé en fonction de l'évaluation finale une fois que la décision d'entreprendre l'étude aura été prise. Le processus continuerait tout au long de l'étude et jusqu'à la fin de l'échéancier du projet et l'obtention de tous les permis nécessaires (environnement et autres). Il faudrait que le financement progresse de la même manière.

Section 3

APPENDIX "A"

STATEMENT OF WORK

OBJECTIVE

To document the principal potentially economic deposits of strontium sulphate (celestite) in Canada summarizing past interest and R&D with regard to major deposits including R&D with regard to the production of strontium carbonate from the MacRae ore at Sydney. Based on previous R&D on MacRae strontium sulphate/strontium carbonate undertake further lab studies and pilot plant investigations to develop improved processing systems for the production of high quality strontium sulphate and strontium carbonate products from this ore. Based on the forementioned results produce a pre-feasibility study detailing the capital and operating costs, returns on investments, for an open pit mine, mill and conversion facility.

REQUIREMENT

The work will be divided into four phases as follows:

Phase I

To document the principal potentially economic deposits of celestite in Canada and summarize past R&D with particular emphasis on the MacRae deposit of Cape Breton Islands, N.S.

Phase II

Based on previous R&D on the MacRae ore, to complete laboratory investigations to:

- (a) identify, develop and investigate improved processes for the concentration and production of strontium sulphate with specifications as follows:

SrSO ₄	90% min
BaSO ₄	1% max
SiO ₂	1% max
Fe ₂ O ₃	0.4% max
PbO	low
	remainder calcium/magnesium sulphates/carbonates

- (b) identify, develop and investigate improved processes for the production of marketable grade strontium carbonate using products derived in (a) above, with specifications as follows:

SrCO ₃	99% min
BaCO ₃	1.0% max
CaCO ₃	0.2% max
MgCO ₃	0.2% max
Na ₂ CO ₃	0.15% max
SO ₄ ²⁻	0.08% max
Fe ₂ O ₃	0.01% max

A 100 ton sample of ore will be crushed, sized and a sample selected for the laboratory work. Tests on ground material will include a preliminary gravity separation study to investigate the removal of barite, and detailed selective flotation studies to produce a concentrate meeting specifications noted in II(a) above. Considerable mineralogical investigations are envisaged, in order to meet these low barite high celestite specifications. The concentrates will be processed through leaching/conversion stages to optimize the grade and

- 2 -

recovery of SrCO_3 . An additional purification stage, may be required to achieve required specifications noted in II(b) above. A full review of Phase II work will be made and a go/no go decision made regarding planned work in Phase III.

Phase III

Based on results developed in Phase II, above,

- (a) to scale-up the developed process for strontium sulphate to pilot plant level; to run pilot plant studies to optimize the production of specification-grade strontium sulphate; to produce a sufficient quantity of concentrates for evaluation by potential consumers.
- (b) to scale up the developed process for strontium carbonate to pilot plant level; to run pilot-plant studies to optimize the production of specification-grade product; to produce a sufficient quantity of specification-grade product for evaluation by potential consumers.
A full review of Phase III work will be made and a go/no go decision made regarding planned work in Phase IV.

Phase IV

By March 30, 1987, and based on the results of Phase I, II and III are geological information obtained from drilling and trenching of the MacRae deposit to produce a pre-feasibility report detailing the capital and operating costs and return on investment. The report would be of sufficient detail to permit an investment decision and would include mining plans, general layout of processing plants, itemize major capital requirements, etc...

APPENDIX «A»

Please amend the Statement of Work as follows:

1. Delete Phase III(b)
2. Revise Phase IV to read as follows:

By March 31, 1987, and based on the results of Phase I, II and III(a); geological and mining information provided by A.C.A. Howe International Limited; and information available from and on file with Phillips Barratt Kaiser Engineering* Ltd., to produce a pre-feasibility report detailing the capital and operating costs and return on investment for a concentration plant to process MacRae celestite to market specifications, and (a) - a conversion plant utilizing the 'carbonate calcining' process, and (b) - a conversion plant utilizing the 'black ash' process, to produce specification grade strontium carbonate. This report would be of sufficient detail to permit an investment decision and would include mining plans, general layout of processing plants, itemized major capital requirements, etc.

*The principal contractor for this project, Chromasco Ltd., will engage P.B.K. Engineering Ltd. to prepare the prefeasibility study and report in co-operation with sub-contractors A.C.A. Howe International Ltd. and J. Bailey McCrea, consultant. Two principals currently with P.B.K. Engineering Ltd. have had 'hands-on' experience with the McRae celestite concentrator and conversion plants operated at Lake Enon and Sydney, respectively, by Kaiser Chemicals from 1969 to 1976.

OK
R. J. Lawrence P. Eng.
for Chromasco, Div. of Timmins Limited

Section 4

REPORT ON
CELESTITE DEPOSITS IN CANADA
WITH EMPHASIS ON
THE MACRAE DEPOSIT, LAKE ENON
CAPE BRETON, NOVA SCOTIA
FOR CHROMASCO LIMITED

By
G.W. Felderhof
A.C.A. HOWE INTERNATIONAL LTD.

DSS File No: 03SQ23440-6-9031
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Part I(a)
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Note: Work on this was conducted under the auspices of the
Canada/Nova Scotia Mineral Development Agreement

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SUMMARY

A.C.A. Howe International Ltd. was contracted by the Chromasco Division of Timminco Limited to document the principal potentially economic deposits of celestite in Canada and summarize past research and development with emphasis on the MacRae Deposit in Cape Breton Island, Nova Scotia. Timminco Limited has been contracted by the Department of Supply and Services of the Federal Government to supply a report encompassing the above information under Contract No. 23440-6-9031/01-SQ.

Twenty five celestite properties are described to varying degrees depending on the level to which the property has been explored or developed. Of these 25 properties only the MacRae Deposit has been explored to the development stage with proven reserves. The remaining 24 properties are all exploration targets which require considerable exploratory work to prove sufficient celestite reserves to consider undertaking metallurgical testing and feasibility studies required for a production decision. These properties are distributed as to 9 in Nova Scotia, of which 7 are in Cape Breton Island, 1 in New Brunswick, 2 in Newfoundland, 1 in Quebec and 5 in Ontario.

Of the 24 exploration properties, the ones with the highest potential include the Amac Property, MacIntyre, Shaw and Monument Prospects, all in the Lake Enon area of Cape Breton Island, Nova Scotia, and the Upper Dorchester Prospect in New Brunswick. The Ronan Prospect in the Port au Port Peninsula of Newfoundland, and the West Bay area of Richmond County, Cape Breton Island, Nova Scotia are also very good exploration targets. These exploration properties are rated highly because the style of mineralization is the bedded or stratiform type which is more likely to attain mineable dimensions.

The Beckwith Property in Cumberland County, Nova Scotia is capable of supplying a small quantity (approximately 500 tons), of high grade celestite for conversion test work.

The MacRae Property has been assessed in detail, with the topics addressed including access, property description, land ownership, history, geology, ore reserves, mining conditions, and products and prices of the previous operator (Kaiser Celestite Mining Limited, a subsidiary of Kaiser Aluminum and Chemical Corp., Oakland, California).

The property comprises 19 claims totalling 760 acres in the Lake Enon (Loch Lomond) area of Cape Breton County, Cape Breton, Nova Scotia. It is located 35 miles south of the City of Sydney and 55 miles north of the town of Port Hawkesbury. Both Sydney and Port Hawkesbury have good port facilities, with Sydney having the best industrial facilities. Access to the property is excellent via paved highways and well kept gravel roads.

The surface rights to the MacRae Property are divided between the Crown and Kaiser Aluminum and Chemical Corporation. The Crown land covers the northern half of the property where the majority of the ore reserves occur, and Kaiser owns the southern half which covers a portion of the old open pit, the waste dump, the settling ponds and the access roads.

The first celestite deposit in the Lake Enon area, the Enon Deposit, was discovered by Lura Corporation in 1962, and acquired and developed by Kaiser Celestite Mining Limited between 1969 and 1971. Kaiser erected a 500 ton per day concentration plant at the mine site and a conversion plant in Point Edward, 35 miles to the north. During the 5½ years of operation Kaiser mined 325,000 tons of ore from four open

pits and underground. The strontium products plant annually produced approximately 14,100 tons of SrCO_3 , 1500 tons of $\text{Sr}(\text{NO}_3)_2$ and 200 tons of $\text{Sr}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ (strontium hydroxide octahydrate).

The mine and products plant closed in 1976, with the reason given as soft markets.

The MacRae Property celestite deposit was discovered in 1973. Geologically the property is underlain by a succession of clastic and chemical sediments - conglomerate, sandstone, siltstone, limestone, celestite and possibly gypsum, (all of marine origin) which rest unconformably on a granitic basement. The rock units strike northeast and dip 15-20° northwest.

A major northwest trending fault crosses the property approximately 500 feet northeast of the ore zones as presently delineated. Secondary faults and brecciation are present in the ore zones and are attributed to the major fault.

The celestite on the MacRae Property occurs as a replacement phenomenon in the rock units and comprises 4 separate zones which have been termed Zone 1, Zone 2, Zone 3 and Zone 4. The celestite zones occur as tabular bodies stacked like a layer cake, one top of the other and separated by units of conglomerate, limestone, etc. The lowest celestite zone is Zone 1 and the highest Zone 4. Zones 1 and 4 are too small and irregular to be of economic interest, however the two intervening zones - Zone 2 and Zone 3 are of economic proportions with respect to size and grade.

Preliminary ore reserve calculations indicate the total undiluted measured reserves are 503,412 tons grading 54.05 per cent SrSO_4 . If only the Zone 3 reserves and the exposed Zone 2 reserves in Pit No. 4 are considered, the total tonnage will be 278,626 tons grading 58.09 per cent SrSO_4 .

The MacRae Celestite Property presently represents the best opportunity for developing a celestite mine if a suitable concentrate can be produced for conversion to strontium compounds. There is a fair possibility that additional open pittable reserves may be found in the Loch Lomond area. There are extensive reserves available through underground mining methods.

There are no known celestite deposits west of Ontario with the exception of the Rexspar property near Kamloops, British Columbia where celestite occurs as a gangue mineral (15 per cent SrSO_4) in a low grade uranium deposit. This property is not a potential source of celestite at the present time due to the low grade nature of the celestite mineralization.

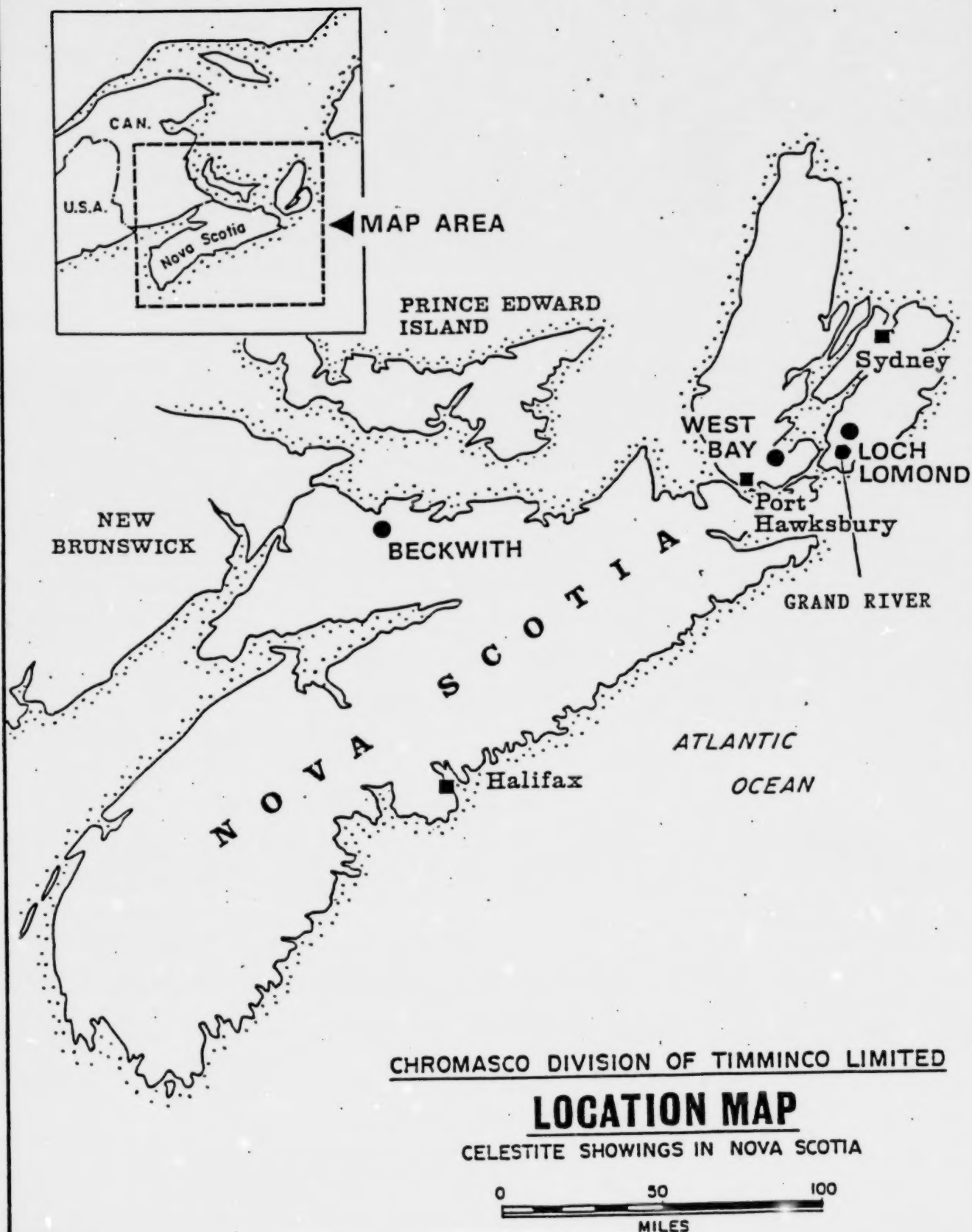
1. INTRODUCTION

A.C.A. Howe International Ltd. was contracted by the Chromasco Division of Timminco Limited to document the principal potentially economic deposits of celestite in Canada and summarize past research and development with emphasis on the MacRae Deposit in Cape Breton Island, Nova Scotia. Emphasis was placed on the MacRae Deposit because it is the largest potentially exploitable celestite deposit known in Canada at the present time.

Timminco Limited has been contracted by the Department of Supply and Services of the Federal Government to supply a report encompassing the above information, under Contract No. 23440-6-9031/01-SQ.

This report is based on:

- (a) relevant government publications,
- (b) data contained in government assessment files, specifically Nova Scotia and New Brunswick,
- (c) data contained in company files,
- (d) information supplied by the Chromasco Division of Timminco Limited,
- (e) personal communication with individuals involved with earlier celestite operations in Cape Breton, Nova Scotia, and
- (f) property examinations made in 1985 and 1986.



CHROMASCO DIVISION OF TIMMINCO LIMITED

LOCATION MAP

CELESTITE SHOWINGS IN NOVA SCOTIA



A.C.A. HOWE INTERNATIONAL LTD.

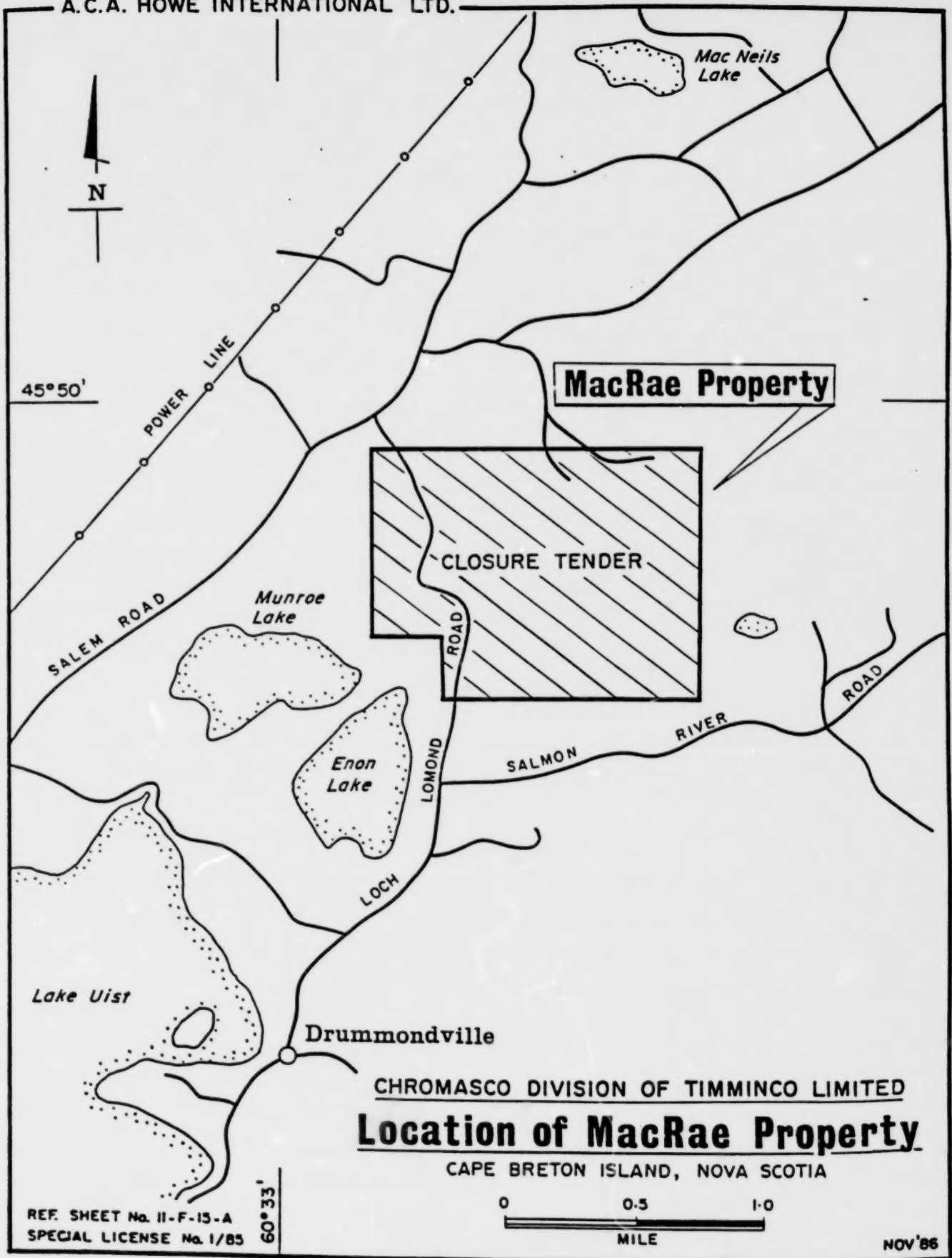


FIGURE 2



Figure 3 - Aerial Photograph
- MacRae Pit area and
Concentrating Plant
- 1:10,000

SUMMARY OF METALLURGICAL
RESEARCH AND DEVELOPMENT WORK
ON CELESTITE WITH EMPHASIS ON
THE MACRAE DEPOSIT
CAPE BRETON, NOVA SCOTIA
FOR CHROMASCO LIMITED

BY

J. Bailey McCrea, P.Eng.
J. BAILEY MCCREA (CONSULTING) LTD.

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1.0 INTRODUCTION

J. Bailey McCrea (Consulting) Ltd., working under the auspices of A.C.A. Howe International Ltd., was contracted by the Chromasco Division of Timminco Limited to summarize the past metallurgical research and development work carried out on the principal celestite occurrences in Canada, with emphasis on the MacRae celestite deposit in Cape Breton Island, Nova Scotia. Timminco Limited had been contracted by the Department of Supply and Services of the Federal Government to supply a report encompassing the above information under Contract No. 23440-6-9031/01-SQ.

This report is based on:

- (a) research of published and unpublished papers contained in files supplied by the Chromasco Division of Timminco Limited,
- (b) information contained in government files, particularly the Nova Scotia Department of Mines and Energy,
- (c) research of relevant metallurgical books and handbooks,
- (d) personal communication with individuals involved with the operation of the first celestite concentrating plant in Cape Breton, Nova Scotia, and,
- (e) examinations of the first celestite concentrating plant in 1985 and 1986.

Research of the available information indicates the following:

- (a) No metallurgical research and development work was done on the MacRae ore other than minor operating modifications undertaken by the "hands on" operators of the concentrator plant just prior to closure in 1976.
- (b) All previous research and development work on Canadian celestite ores was done on the Enon celestite deposits located near the concentrator in Cape Breton, which are silica based - i.e. sandstone hosted.
- (c) Excluding research and development work on Canadian (Enon) celestite ores, the balance of available information pertinent to future work is contained in the general metallurgical literature.

2.0 PREAMBLE

Strontium sulphate (celestite) was first isolated by Davy in 1808; but the carbonate (strontianite) had only been known since 1855 when it was prepared from strontium sulphate by conversion in an alkali solution. Strontium carbonate was technically made when strontium sulphate was fused with sodium carbonate. It exhibits chemical characteristics similar to calcium carbonate, however it is even less soluble in water. Its solubility is greater in the presence of carbon dioxide. (Parks, 1912).

Celestite's specific gravity is 3.96 and its hardness 3 to 3.5. It decomposes at 1580°C. Celestite's solubility in water at 0°C is 113 mg/l, and 111.4 mg/l at 32°C. It is insoluble in dilute H_2SO_4 (Perry, 1963).

Strontium carbonate's specific gravity is 3.70. Its solubility in cold water (18°C) is 11 mg/l and 650 mg/l in hot water (100°C); it is soluble in acids, NH_4 salts, and aqueous CO_2 (Perry, 1963).

3.0 BENEFICIATION

3.1 PRE 1960's RESEARCH

Little was known about celestite beneficiation before 1969 due to the rich ore bodies being mined in parts of the world without the need for concentration. Taggart (1944), in his Handbook of Mineral Dressing of Ores and Industrial Minerals, states that in "Reports of Investigation, U.S. Bureau of Mines" 3628, celestite was floated from calcite and strontianite at <200 mesh and 30% solids using quebracho, oleic acid, and a higher alcohol frother.

In general Taggart reports that non-silicate minerals of alkali and earth metals comprise a large group of soluble and relatively insoluble salts of which celestite is typical. Flotation was usually affected by soap flotation, formed by hydrolysis of a fatty acid in the presence of an alkali. The soap ion displaces the acid ion of the mineral, thus allowing the coating reaction to occur. Taggart also states that desliming is necessary when it is impossible to prevent collector coating of gangue slime.

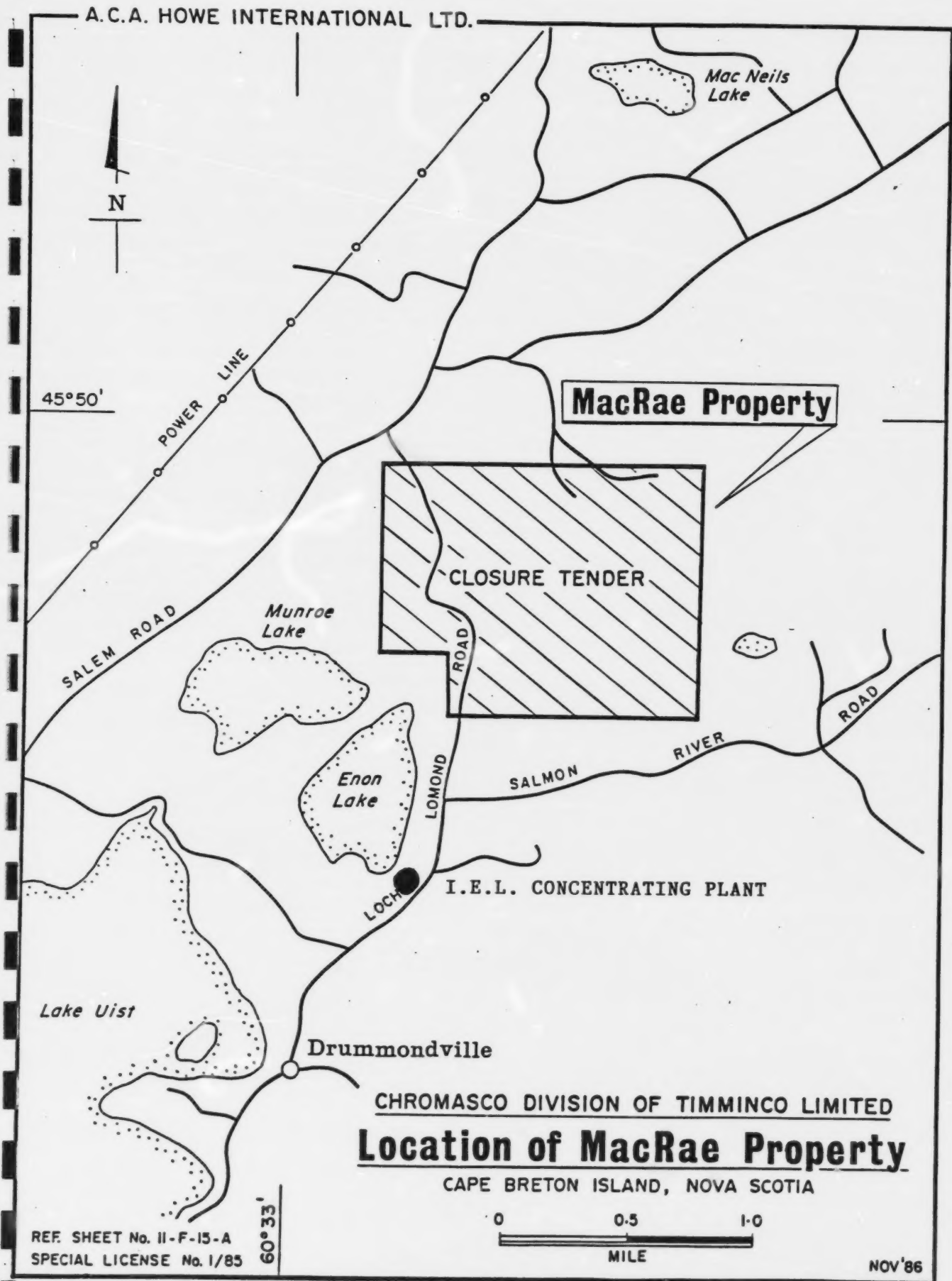
3.2 LAKE ENON CELESTITE

The favourable market for strontium compounds in the late 1960's stimulated the investigation of low to medium grade (40 - 60 per cent SrSO_4), celestite deposits in the Loch Lomond region of Cape Breton, Nova Scotia for possible upgrading to meet chemical industry specifications. The first of these celestite deposits identified for development were silica hosted and were subsequently known as the Enon deposits which were mined from Pits 1, 2 and 3. The fourth and last deposit developed prior to mine closure was the MacRae deposit which is limestone hosted and partially mined from Pit 4 (Figure 1).

Prior to commencing commercial production, the property's owner, Kaiser Aluminum and Chemical Corporation, commissioned research on the concentration of silica hosted celestite and conversion of the concentrate to SrCO_3 .

Celestite deposits of the Lake Enon area were described to have sandstone, limestone, salt, blue clay, fault gouge, shale and shale type mudstone within the deposits, as well as layers of these products above and below the celestite layers. The Lake Enon ore contained higher ratios of silica to calcium carbonate than MacRae ore (Forgeron, 1977).

A.C.A. HOWE INTERNATIONAL LTD.



REF. SHEET No. II-F-15-A
SPECIAL LICENSE No. 1/85

CHROMASCO DIVISION OF TIMMINCO LIMITED
Location of MacRae Property
CAPE BRETON ISLAND, NOVA SCOTIA

NOV'86

FIGURE 1

3.3 HEAVY MEDIA TEST

The first concentration test work was undertaken by Hazen Research in 1963 and centered on heavy media separation in an effort to exploit the contrast in specific gravity between the principal gangue minerals and celestite. The results were negative (Crowel, 1971).

3.4 FATTY ACID FLOTATION

Following heavy media separation trials, fatty acids were used with suitable results (separation of celestite from silicates occurred), during a laboratory investigation at Nova Scotia Technical College and at Hazen Research (N.S. Department of Mines and Energy, 1985). Using feed of 87.43 per cent SrSO_4 , 0.40 per cent BaSO_4 , 0.36 per cent CaSO_4 , and 11.81 per cent combined water/carbonates/alumina/other impurities. Results gave 95 per cent SrSO_4 at 86 per cent recovery using the siliceous based ore (Enon ore). Upgrading with dilute hydrochloric acid wash gave 98.6 per cent SrSO_4 with 0.5 per cent BaSO_4 and less than 1 per cent impurities (Routil, 1968). Although these results were excellent, they were unrealistic due to feed grades being lower during actual operation of the concentrator.

Research was continued at the Nova Scotia Technical College laboratory under the Atlantic Industrial Research Institute (AIRI) in association with CANMET.

3.5 ADDITIONAL FLOTATION WORK

CANMET and Atlantic Industrial Research Institute assessed hundreds of organic reagents and discovered Igepon T33 to be an excellent collector for barite. It was then used for celestite flotation with similar results (Hartman, 1971).

Pilot plant testing at AIRI confirmed CANMETS's findings (N.S. Department Mines and Energy, 1985) consequently Igepon T33 replaced the original fatty acid in the plant.

Changing conditions on site at the Kaiser concentrator brought on the replacement of Igepon T33 by Pamak C (a fatty acid), and then by Cyanamid R-845 (petroleum sulphonate) (McCrea, 1985).

3.6 DESLIMING

No research dealing specifically with desliming of Enon celestite ores was found. Desliming before and after stage grinding is usually necessary in non-metallic flotation for reagents to function efficiently.

Clays in the ore as well as slimes produced in grinding caused the majority of the problems in the concentrator. The operators removed clays and slimes at the thickener, thereby defeating its purpose. This compromised flotation with residual fines resulting in below-grade SrSO_4 concentrate and poor recovery. Desliming by cyclone or separator was not implemented (McCrea, 1985).

A single ball grinding stage was used in the Kaiser concentrator, necessitating excess use of silicates as reported by operating personnel, which in turn generated additional problems through the concentrating plant, giving uneven final celestite grade. This also resulted in high expense in dewatering and filtering and lower final celestite grades (N.S. Dept., 1985), (McCrea, 1985).

Semi-autogeneous grinding utilizing only a small load of balls was run with poor results. Sandstone gangue gave too coarse a grind consequently the concentrator returned to ball grinding (McCrea, 1985).

3.7 ION APPLICATIONS

No research dealing with earth metal ion activity in flotation of Enon celestite ores was found. The relationship of the strontium ion, the barium ion, and the calcium ion to the floating or depressing of their sulphates were not considered.

Earth metal ions, such as calcium, magnesium, barium and strontium, consume reagent, especially fatty acid collectors, by precipitating as insoluble soaps. These soaps smear all particles indiscriminately and carry them into the froth in flotation cells (Fuerstenau, 1962).

The carbonate ion is used as a precipitant for earth metals to prevent resurfacing (Taggart, 1944).

Ba ions added as BaCl_2 , increases the floatability of BaSO_4 (activation). BaCl_2 at 69.1 mg/l, along with K_2CrO_4 at 310.7 mg/l, defeats the depressing effect of K_2CrO_4 and allows barite to float. SrCl_2 will act similarly with celestite. CaCl_2 will allow both celestite and barite to float.

Versene chelating agents, such as polycarboxylic acid salts, tie up metallic ions that cause flotation of unwanted materials (Dow Chemical, 1968).

3.8 REAGENTS

3.8.1 INTRODUCTION

Reports on previous research on Enon celestite ores did not specifically discuss collectors, depressants, activators and silicates, (a dispersant and depressant) in their different environments. However, because of their relevance to celestite flotation, the following is a synthesis of information taken from various sources.

3.8.2 COLLECTORS

All cationic collectors are surface active and in slimy pulps tend to form voluminous persistent froths that cause difficulty in product thickeners and thus increases operating costs. Cationics are sensitive to soluble salts and to slimes (Fuersteau, 1962).

Reverse cationic flotation of quartz, kaolinites (clays), and soluble halides is possible but is difficult due to the coarseness of the quartz and calcite compared to celestite. The flotation would not be selective due to fine celestite entering the froth (Gaudin, 1939).

Water softening increases dispersal of slimes and can reduce excessive collector use by eliminating dissolved calcium and magnesium ions using carbonate as a regulator (Taggart, 1944).

Alkaline phosphates assist the recovery of non-metallic minerals in soap flotation; they also soften water (Fuerstenau, 1962).

Reagents to separate calcite and barite from celestite are Al_2O_3 , FeCl_3 , citric acids, and cyanamids such as Aero Promoters, Aeromines, etc., for alkaline earth compounds (Cyanamid, 1970).

Anionic collectors are also collectors for common gangue constituents such as iron oxide or calcite (Gaudin, 1939).

3.8.3 DEPRESSANTS

Lignin sulphonates, particularly the calcium salt, are recommended for depression of carbonaceous gangues with fatty acid, sulphydric, and cationic collectors (Taggart, 1944).

Citric acid depresses quartz, mica, fluorspar, carbonates, and iron oxides from barite (Fuerstenau, 1962).

Aluminum sulphate or aluminum chloride has a depressing effect on calcite and certain other non-metallic minerals, but activates quartz (Taggart, 1944).

Quebracho is a highly effective dispersant for slime gangue in soap flotation and is reported as more dependable and less difficult to handle than metal salt-silicates in depressing calcite from barite. Excess amounts depress all minerals with the optimum quantity of reagent varying with collector used, pulp density, and pH. Because of the difficulty in controlling these variables, quebracho is a difficult reagent to manage in flotation cells as reported by Taggart. In addition, all heavy metal salts must be precipitated or complexed before the addition of quebracho, since the reaction products (heavy metal tannates) are powerful depressants of all earth metal minerals. This can be used as a depressant for celestite in reverse flotation, but quebracho in excess will cause excessively high collector consumption (Taggart, 1944).

It is known that depression of barite by chromates occurs with the anionic collector Cyanamid R-845 during fluorspar flotation at a pH of 10. Chromates supplement caustic starch for calcite/barite depression (Fuerstenau, 1962). It is noteworthy however that the higher the tailings pH, the higher the chromate ion in solution, which is environmentally undesirable.

Cyanides depress quartz and other silicates (Cyanamid, 1970).

Aluminum sulphate or chloride has a depressing effect on calcite but can activate quartz (Cyanamid, 1970).

3.8.4 ACTIVATORS

Ferrous and ferric sulphates tend to active quartz and in addition interferes with the selectivity in many non-metallic separations (Cyanamid, 1970), (Fuerstenau, 1962).

Hydrogen sulphide activates lead carbonates (Cyanamid, 1970).

Ferrous and ferric salts aid recovery of galena depressed with dichromate (Cyanamid, 1970), (Fuerstenau, 1962).

3.8.5 SILICATES

Soluble silicate is the reagent most widely used to depress quartz and most silicate minerals, and to disperse siliceous and iron-oxide slimes (Fuerstenau, 1962).

3.9 REGULATORS PERTINENT TO ENON ORES

Celestite, calcite, silica and barite are the principal components of Enon celestite ores, each of which is susceptible to certain regulators. These regulators have been summarized very well in Mining Chemicals Handbook of Cyanamid (1970), and are described below.

Celestite regulators (for slime, ion build up, quartz depressant, calcite depressant) are sodium silicate and sodium carbonate. A depressant is quebracho. Anionic collectors are Cyanamid 700 series, oleic acids or Cyanamid 800 series or Pamak. Frothers are Aerofroth, Dowfroth (tenacious), pine oil, cresylic acids (Cyanamid, 1970).

Barite regulators are sodium silicate and sodium carbonate. Depressants are $AlCl_3$, $FeCl_3$, and Cyanamid 600 series. Barite collectors are the Cyanamid 700 and 800 series, oleic acids, and the higher alcohol sulphates. Frothers are Aerofroths, pine oil, and cresylic acid. A selectivity assisting agent is citric acid (Cyanamid, 1970).

Calcite regulator is sodium carbonate. Depressants are quebracho, tannic acid, sodium silicate, and dichromate. An activator is heated pulp. Collectors are the 700 and 800 series, oleic acid, fatty acid residues, and heavy fuel oil. The frother is Aerofroth. For better selectivity, R-610 depressant can be used for gangue slimes (Cyanamid, 1970).

Silica regulator is natural pH. Depressants are sodium silicate, hydrofluoric acid, citric acid, and sulphuric acid. Collectors are Aeromine in acetic or hydrochloric acid, and cationic collectors. Frothers can be Aerofroth

or pine oil. Collector assistant aids can be fuel oil or kerosene in small amounts to help cut the tenacious frothing characteristics of some collectors. Activators are lime and sodium silicate in excess. Depressants include the 600 Cyanamid series, dextrin, starch, and lignin sulphonates (Cyanamid, 1970).

3.10 COLLOIDS

Colloidal particles were not identified at the concentrator but were eliminated at the conversion plant.

Colloidal iron group of impurities can not be removed with flotation but necessitates an acid wash (Pryor, 1965).

3.11 BASE METAL GANGUE

There is no known research dealing specifically with the problems of base metal gangue in Enon celestite ores. This is significant in that the MacRae ore has a lead component which must be considered.

Lead and iron compounds can be prefloated with Z-200 or xanthates (Pryor, 1965), (Dow, 1968).

3.12 OPERATORS IN THE KAISER CONCENTRATOR

The concentrator upgraded an ore assaying 35 to 65 per cent SrSO_4 to a concentrate of 80 to 85 per cent SrSO_4 and occasionally assaying 90 to 91 per cent SrSO_4 , giving a varied feed to the conversion plant (McCrea, 1985). The conversion plant was therefore receiving a concentrate which was not meeting specifications (90% SrSO_4) most of the time.

Total reclaim water was used without any knowledge of the effect of the ion buildup on the depressants, modifying agents, and collector reagents in the flotation cells (McCrea, 1985).

Scavenger concentrate was returned to the conditioning tank, not to a classifier/grinding unit as it should be if true middling particles existed (McCrea, 1985).

Inclusions of calcite were found in celestite. The mode of occurrence of barium was not known at that time and appears not to have been important to the operators. (McCrea, 1985).

Only one stage of filtering (disc filter), was implemented. This in turn restricted output due to sliming and prevented the washing out of reagents from the concentrate. Dual filtering would effect the required water washing for reagents removal (McCrea, 1985).

Frozen ore from the stockpile caused complications in steady feed requirement to the beneficiation system. Gouge and clays at other times disrupted the feed. Mill results, for an example, in June of 1976 were: rougher feed containing 53 per cent celestite; rougher concentrate showing 77 per cent: 1st cleaner at 84 per cent; 2nd cleaner at 87 per cent; 3rd cleaner concentrate at 89 per cent; and finally 4th cleaner at 90 per cent celestite; all with tailings at 25 per cent grade of celestite, giving a 73 per cent recovery. These good results were infrequent due to the flotation feed conditions of high slime and fault gouge (N.S. Department of Mines and Energy, 1985).

Low CaCO_3 (limestone) in celestite concentrate was beneficial to strontium carbonate final grade. The operating personnel knew that lowering the limestone content was imperative but could not operate their plant efficiently when limestone gangue was high (McCrea, 1985).

Research before 1968 shows that both iron and silica impurities in the celestite concentrate lowers conversion recovery by forming strontium compounds which precipitate strontium before the carbonate is formed. During conversion operations at Sydney, Nova Scotia, the volume of the iron group impurity was found to be important also, due to the colloidal precipitate plugging up de-watering systems which in turn caused countless problems which were only solved by the purchasing of expensive equipment, raising operating costs.

3.13 MACRAE ORE

The original testwork was performed on a siliceous gangue ore from the Enon pits. When new ore arrived from the MacRae pit (No. 4), Zone 2, during the latter part of the concentrator's operation, the base gangue was limestone not silica. This presented the operators with a different set of parameters for flotation. No prior research was done on this MacRae ore which contains celestite ores in the following range of grades: 49 to 84 per cent celestite with impurities of 1 to 4 per cent barite, 16 to 30 per cent limestone, 14 to 16 per cent sandstone, 1 to 1.4 per cent hematite, and 0.5 per cent lead impurities (McCrea, 1985).

This high limestone gangue content forced the sodium silicate consumption to be doubled, making flotation of this ore unmanageable with recoveries in the range of 55 to 70 per cent.

If research had been performed prior to the limestone based ore being sent to the concentrator, superior results would probably have been attained (McCrea, 1985).

4.0 CONVERSION

4.1 INTRODUCTION

Investigations revealed that little information is available pertaining to the research and development relating to conversion of Canadian sourced celestite or celestite concentrate to strontium carbonate. The available information on the only conversion plant that operated in Canada (Kaiser Chemicals Ltd., Point Edward, Cape Breton, Nova Scotia), is contained in three patents taken out by that company.

The following is a synthesis of information taken from these patent descriptions and from various sources acknowledged throughout the text.

4.2 METATHESIS

Metathesis reactions or double decomposition reaction of the type $AC + BD \rightarrow AD + BC$ are described in Perry's Chemical Engineers' Handbook, in 1963. It is possible to carry out such reactions continuously as long as one product is soluble and the other insoluble (Perry, 1963), (Newth, 1903).

Barium sulphate can be formed into a crude barium sulphide. This then is heated in a stream of moist carbon dioxide, whereby it is converted into the carbonate. The family of earth metal non-silicates were known to follow similar reactions when Berthier, in 1823, prepared strontium sulphide by reduction of strontium sulphate with carbon (Newth, 1903).

Conversion of celestite to strontium carbonate based on their respective solubilities as a driving force, occurs using Na_2CO_3 , K_2CO_3 , $(NH)_2CO_3$ or ammonia and carbon dioxide in hot water (Taylor, 1948), (Parks, 1940).

In addition, it was known that when strontium sulphate was boiled with solutions of alkaline carbonates, strontium sulphate is completely converted to strontium carbonate (Newth, 1903).

Finely divided celestite is reacted with aqueous sodium hydroxide at temperature just below the boiling point. Solids produced are separated, washed in cold water, filtered and then dissolved in hot water. This hot solution is filtered to remove any other solids, and the filtrate is reacted with carbon dioxide to precipitate strontium carbonate (Canadian Patent 1017533).

4.3 CHLORIDES

The elimination of sulphate, silica and silicate impurities by dissolving strontium carbonate in hydrochloric acid, and the elimination of aluminum and iron impurities from their soluble salts by the addition of ammonium hydroxide was known before 1960. Nevertheless, the dissolution of strontium carbonate in hydrochloric acid as a purification technique was not practised at the Kaiser Chemicals Ltd. conversion plant at Point Edward, Cape Breton.

Prior to 1903 strontium chloride was formed by the action of hydrochloric acid on strontium carbonate (Newth, 1903). Strontium nitrate (which crystalizes with four molecules of water) was produced by adding strontium chloride to sodium nitrate solutions (Taylor, 1948).

Partial precipitation of calcium from strontium carbonate contaminated with calcium carbonate by adding ammonium oxalate was known (Taylor, 1948).

4.4 PYROTECHNIQUES

The Kaiser Chemicals Ltd. concentrating plant operated at Point Edward, Cape Breton utilized a "White Ash" method to upgrade crude strontium carbonate to refined strontium carbonate.

Strontium carbonate was calcined in a rotary kiln without excessive liquid formation when admixed with at least 8 per cent finely divided carbon and the kiln operated with not less than 2 volume per cent combustables in the exit gases. At least 95 per cent of the strontium carbonate feed passed a 325 mesh screen. Under these conditions, the mixture of strontium carbonate and carbon forms agglomerates soon after entering a kiln, minimizing premature burning of the carbon and preventing the sticking of strontium carbonate to the kiln wall. The previous operation at Sydney, used a horizontal rotating cylindrical kiln type furnace, using a reducing atmosphere produced with an excess of carbon mixed with the strontium carbonate feed. Temperatures were kept within a narrow range, with a partial oxidizing area at the tail end of the kiln. Strontium oxide, being produced, was dissolved in water, with impurities remaining in solid form. This process was given as public knowledge (reports to CIMM, etc.) in 1969, whereas patents were granted in 1975 (Canadian Patent 965578), (McCrea, 1985).

The so-called Black Ash commercial process for converting strontium sulphate to strontium carbonate entails mixing strontium sulphate with finely divided carbon and calcining the mixture at a temperature of about 1000° C to produce strontium sulphide, carbon dioxide, carbon monoxide, and impurities which were present in the original ore. The strontium sulphide is then dissolved in water with the solid impurities being removed. The strontium sulphide in solution is converted to the carbonate by carbonation, either with sodium carbonate, which produces sodium sulphide as a

waste disposal byproduct, or carbon dioxide which produces hydrogen sulphide, an undesirable pollutant, or both the above which produce sodium hydrosulphide as a waste product (Stone, 1969).

The original Black Ash method was actually described as the Leblanc Process (Taylor, 1931), for making sodium carbonate from sodium chloride using sulphuric acid at red heat and mixing the resultant sodium sulphate with chalk, coal and coke in a rotating furnace. The sulphate was reduced to sulphide, which then reacted with the calcium carbonate, to form sodium carbonate and calcium sulphide (insoluble in water).

Sodium carbonate was crystalized out after solids separation.

Strontium sulphate is added to a solution of sodium carbonate to produce strontium carbonate and leave sodium sulphate in solution. Very little purification takes place during this process. Strontium carbonate is calcined to produce strontium oxide, hydrating the oxide, then dissolving in water, separating any insoluble material, then carbonating the strontium hydroxide to precipitate strontium carbonate (Canadian Patent 1003188).

Due to environment reasons, it is difficult to use pyrotechniques with hydrogen sulphides or sulphur dioxide gases being produced. More so, the direct conversion in water alleviates most of the stringent environmental difficulties, however this method necessitates consistently high grade celestite concentrate.

4.5 SOLVENT EXTRACTION PROCESSES

Very little, if any, research has been conducted on solvent extraction processes at the commercial scale.

A solvent extraction process has been devised using di(2-ethylhexyl)orthophosphoric acid (D2EHPA) diluted with tri-n-butyl phosphate (TPH) and Shell spray base to extract Sr ions from a crude strontium nitrate concentrate solution; then stripping with citric acid to obtain the purification. Further purification can occur with the use of a cation exchange resin, with a nitric acid strip (Schulz, 1963).

Strontium sulphate can be dissolved in sodium hydroxide at elevated temperatures, with the resulting strontium hydroxide being extracted from the solidified fusion with an ethylene glycol and methanol solvent.

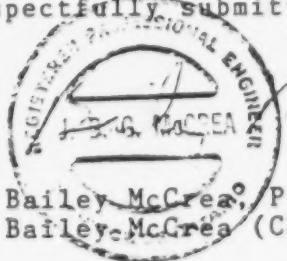
4.6 OBSERVATIONS

Some of the pros and cons for liquid conversion were known previous to 1969. Both liquid and calcining benefit from dilute acid prewash. Liquid conversion requires more expensive reagent than heat conversion. Heat conversion requires higher energy cost than liquid conversion. Both conversion methods have difficulty lowering contaminants from low grade celestite feed. Heat conversion is "very touchy" reported by previous operations at Sydney (McCrea, 1985).

5.0 CONCLUSIONS

- A. An inadequate data base exists with respect to beneficiation of celestite ores and conversion to strontium carbonate to allow any commercial operation to begin in Canada on the known (Enon, but not MacRae) celestite deposits.
- B. The more stringent grade specifications required by markets today, compared with the early 1970's, do not permit the commercial production of strontium carbonate under previously developed processes.
- C. The MacRae ore gangue matrix differs considerably from the Enon ore mined by earlier operators, and as such the beneficiation process utilized by these operators is not applicable to the MacRae ore, thereby necessitating modification by further research.

Respectfully submitted,



J. Bailey McGree, P. Eng.
J. Bailey McGree (Consulting) Ltd.

REFERENCES AND BIBLIOGRAPHY

- | | |
|--|--|
| Canadian Patent
965578
1975 | Purification of Strontium Carbonate,
16 p. |
| Canadian Patent
1003188
1973 | Calcination of Strontium Carbonate,
16 p. |
| Canadian Patent
1017533
1973 | Extraction of Strontium Values from
Celestite, 12 p. |
| Coope, B.M.
1983 | A Profile of Proinsur; Industrial
Minerals, September, 69-71. |
| Crowell, G.D.
1971 | The Kaiser Celestite Operation at Loch
Lomond; CIM Bulletin for October, 48-52. |
| Cummings, A.B.
Given, I.A.
1973 | Mining Engineering Handbook. |
| Cyanamid of Canada
1970 | Mining Chemicals Handbook, 80-95; 123 p. |
| Dana, E.S.
1898 | A Textbook of Mineralogy, 353-364; 523-527. |
| Dennis, W.H.
1961 | Metallurgy of the non-ferrous metals, 711 p. |
| Dow Chemical
1968 | Flotation Fundamentals and Mining
Chemicals , 112; 117 p. |
| Forgeron, S.
1977 | The Kaiser Celestite Mining Operation
and Mineral Potential of the Loch Lomond
Basin, Cape Breton, Nova Scotia, 105 p. |
| Fuerstenau, D.W.
1962 | Froth Flotation , 50-69, 179, 201; 677 p. |
| Gaudin, A.M.
1939 | Principles of Mineral Processing, 554 p. |
| Glockler, G.
Glockler, R.C.
1947 | Chemistry In Our Time , 667 p. |

- Hartman, F.H.
Wyman, R.A.
1971
Beneficiation of Celestite from Cape Breton, Nova Scotia; Department of Energy, Mines and Resources, Rpt. IR-71-20,59p.
- McCrea, J.B.
1985
Nova Scotia Venture (Trip Report, November 8, 9, 10 to Cape Breton, Nova Scotia), 16p.
- N.S. Dept. of
Mines & Energy
1985
Processing of Cape Breton Celestite Ore, 20p.
- Newth, G.S.
1903
A Textbook of Inorganic Chemistry, 577-589.
- Parkes, G.D.
1912, 1940
Mellor's Modern Inorganic Chemistry, 616-639.
- Peele, R.
1918
Mining Engineers Handbook, 2-27; 2229 p.
- Perry, J.H.
1934, 1963
Chemical Engineers Handbook, 3-4 to 322, 17-45 to 47.
- Pirsson, L.V.
1908, 1947
Rocks and Rock Minerals, 339 p.
- Pryor, E.J.
1965
Mineral Processing, 844 p.
- Richards, R.H.
Locke, C.E.
1925
A Textbook of Ore Dressing, 95-102, 264-310.
- Routil, R.J.
1968
Chemical Composition and Possible Industrial Applications of Celestite from the Loch Lomond area of Nova Scotia; Nova Scotia Technical College, 18 p.
- Schulz, W.W.
Mendal, J.E.
Richardson, G.L.
1963
Solvent Extraction Recovery and Purification of Strontium-90; I & EC Process Design and Development, 134-140.
- Spence, H.S.
1922
Barium and Strontium in Canada; Canada Department of Mines, 32158; No.570, 68 p.
- Stone, W.J.D.
1969
An Integrated Mining and Chemical Plant Complex for Various Strontium and Barium Products; CIM Bulletin, October 1083-1086.

Taggart, A.F.
1927, 1944

Handbook of Mineral Dressing, 3-06 to 09,
10-09 to 16, 12-01 to 37, 12-121 to 128, 1915 p.

Taylor, F.S.
1931, 1948

Inorganic and Theoretical Chemistry,
250-268, 320-354.

Toon, E.R.
Ellis, G.L.
1978, 1983

Foundations of Chemistry, 769 p.

U.S. Patent
1975

Calcination of Strontium Carbonate, 4 p.

XIV International
Mineral Processing
Congress
1982

Worldwide Industrial Application of
Mineral Processing Technology, Sessions
I to X, six volumes.

CERTIFICATE

I, J. Bailey McCrea, of 67 Grassington Crescent,
Brampton, Ontario, hereby certify that:

1. I am and have been employed since 1980 as a metallurgist by J. BAILEY MCCREA (CONSULTING) LTD. with office at above address.
2. I am a graduate of the Technical University of Nova Scotia (NSTC), Halifax, Nova Scotia, with a Bachelor of Engineering (1967) degree in Minerals Dressing and Metallurgy.
3. I am a member and have been designated as a consulting Engineer by the Association of Professional Engineers of Ontario.
4. I am a member of the Prospectors and Developers Association of Canada and a member of The Canadian Institute of Mining and Metallurgy of Canada.
5. I have practiced my profession in excess of nineteen years.
6. This report is based on government reports, technical books, other published reports both on the continent and off, communications with various past operators of the previous concentrating plant and metathesis refinery, and visits to the mill property of the past celestite operations.
7. I have no interest in Chromasco Limited.

Brampton, Ontario
October 22, 1986


J. Bailey McCrea, P. Eng.
J. BAILEY MCCREA (CONSULTING) LTD.

Section 5

An Investigation of
THE RECOVERY OF STRONTIUM

from MacRae ore samples

submitted by

CHROMASCO

(A Division of Timminco Ltd.)

Volume No. 1

Lakefield Project No. LR 3171

Work on this project was conducted under the auspices of
the Department of Energy, Mines and Resources

DSS FILE NUMBER:	03SQ.23440-6-9031
DSS CONTRACT NUMBER:	23440-6-9031/01-SQ
EMR SCIENTIFIC AUTHORITY:	R.K. Collings, Head, Non-Metallic Minerals Section Canada Centre for Mineral and Energy Technology 405 Rochester Street, Ottawa, Ontario. K1A 0G1.

NOTE:

This report refers to the samples as received.

The practice of this Company in issuing reports of this nature is to require the recipient not to publish the report or any part thereof without the written consent of Lakefield Research.

LAKEFIELD RESEARCH
A Division of Falconbridge Limited
Lakefield, Ontario
December 17, 1986

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DETAILS OF TESTS

Flotation Zone 3
Flotation Faulted Zone
Celestite Acid Leach
Strontium Carbonate Production
 Conversion
 Dissolution and Purification
 SrCO₃ Precipitation

APPENDIX NO. 1

Barium Mineralogy : RPC Report
Number MDP/86/05

APPENDIX NO. 2

Lead Mineralogy : RPC Report
Number MDP/86/08

APPENDIX NO. 3

Sedigraph Analyses on SrCO₃ Precipitates
Indusmin Technical Center : File C-176

A B S T R A C T

MacRae celestite ore with a head assay of 70 % SrSO_4 was upgraded by flotation to 90-95 % SrSO_4 at 80-85 % recovery in batch tests.

Barium was present in solid solution in the celestite and was concentrated to 1.2 - 1.4 % BaSO_4 in the flotation concentrate. The flotation concentrate also assayed 0.1 - 0.2 % Pb which was present mainly as PbCO_3 and $(\text{Pb},\text{Sr})\text{CO}_3$.

The celestite concentrate did not meet the market specifications of less than 1 % BaSO_4 and low Pb, preferably nil.

A hydrometallurgy treatment process was developed to produce market grade strontium carbonate from the celestite concentrate.

The process consisted of the following major stages with intermediate solid/liquid separation:

1. Celestite acid leach
2. Conversion of celestite to crude SrCO_3
3. Dissolution of the crude SrCO_3 in HCl and purification of the SrCl_2 solution
4. SrCO_3 precipitation

The strontium carbonate precipitates from the current testwork had the following analyses:

Composite	Assay	Spec.
SrCO_3 %	99.0	>99.0
BaCO_3 %	0.1-0.2	<1.0
CaCO_3 %	0.5-0.6	<0.2
MgCO_3 %	0.01-0.02	<0.2
Na_2CO_3 %	0.2-0.4	<0.15
Fe_2O_3 %	<0.01	<0.01
Al_2O_3 %	<0.01	-
SiO_2 %	<0.1	-
S %	<0.05	<0.04
Pb %	0.02-0.05	-
Zn %	0.003-0.004	-

Abstract - Continued

The calcium and lead contents of the SrCO_3 precipitate could be reduced with improved purification of the SrCl_2 solution.

Careful control of the precipitation stage and thorough washing of the precipitate would be necessary to achieve the sodium specification of $<0.15\% \text{Na}_2\text{CO}_3$ in the SrCO_3 product.

The overall flowsheet for the process is contained in Figure No. 1.

FIGURE NO. 1 - OVERALL FLOWSHEET

- 6 -

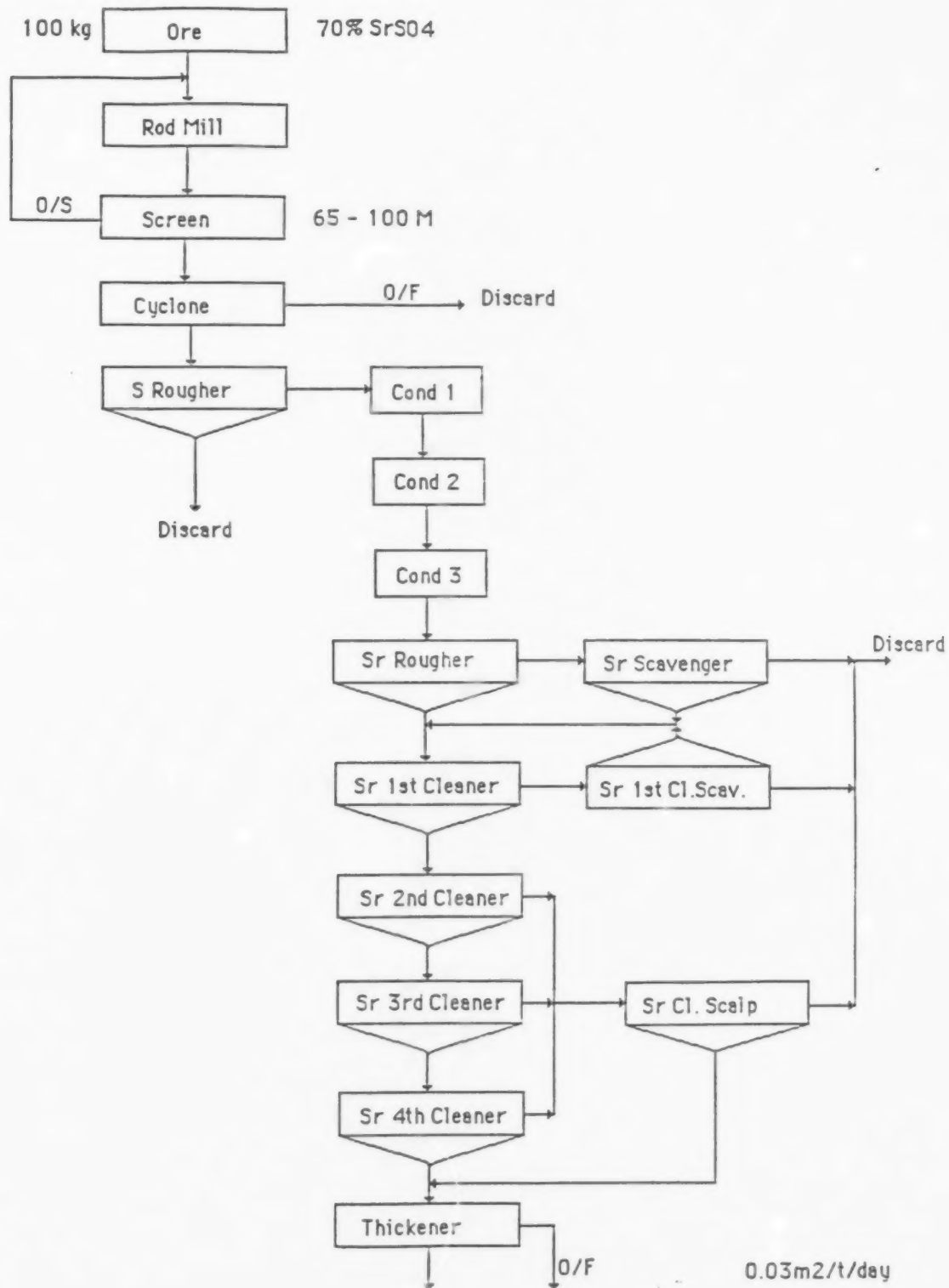


Figure No. 1 Cont'd

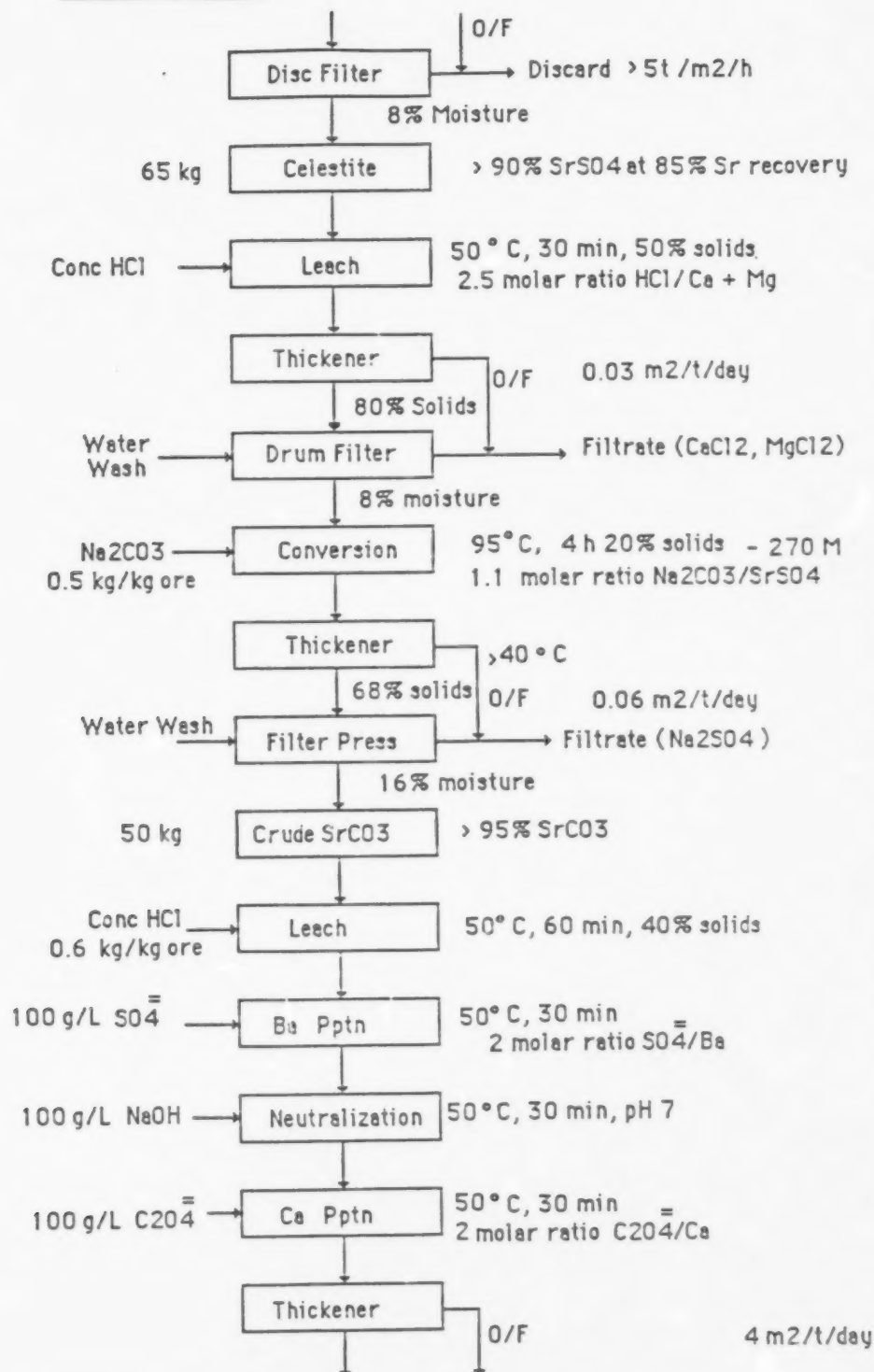
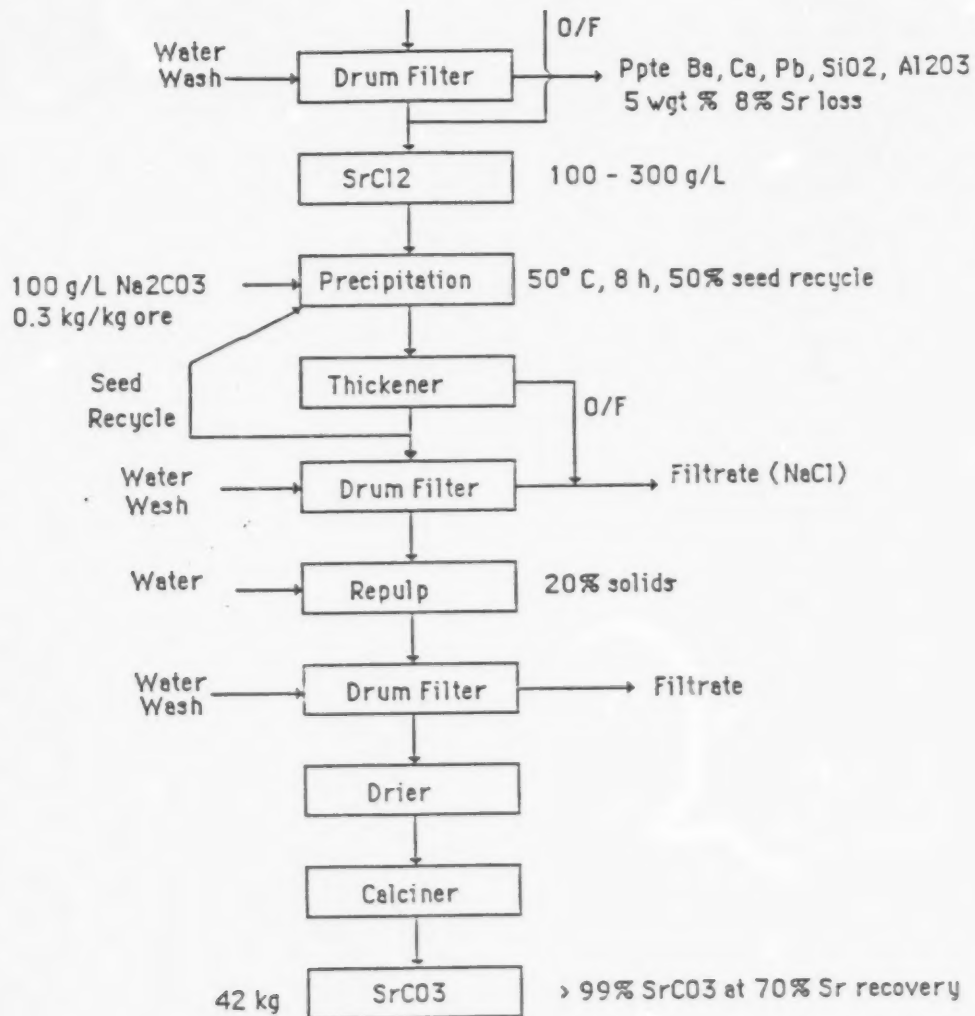


Figure No. 1 Cont'd



INTRODUCTION

A laboratory testwork program was conducted on MacRae celestite ore to concentrate the ore to the following specifications:

90 % SrSO_4 min
1 % BaSO_4 max
1 % SiO_2 max
0.4% Fe_2O_3 max
0.1% CaCO_3 max
0.1% Al_2O_3 max
low Pb and Zn

A hydrometallurgical process was developed to convert the celestite concentrate to market grade strontium carbonate:

99 % SrCO_3 min
1 % BaCO_3 max
0.2% CaCO_3 max
0.2% MgCO_3 max
0.15% Na_2CO_3 max
0.04% S max
0.01% Fe_2O_3 max

The objectives were outlined in Chromasco P.O. No. H-2720-80 referenced to DSS File No. 03-SQ23440-6-9031.

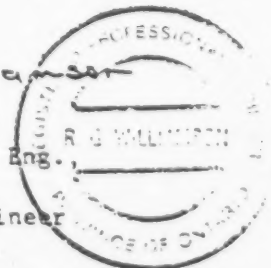
LAKEFIELD RESEARCH

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Senior Project Engineer



Experimental Work by: S.J. Parker
Zhang Li-Cheng

SUMMARY

1. Head Analyses

Representative samples were removed from each ore for analysis.

<u>Component</u>	<u>Zone 3</u>	<u>Faulted Zone</u>
SrSO ₄ %	72.4	69.9
BaSO ₄ %	1.06	1.12
CaCO ₃ %	13.4	13.5
MgCO ₃ %	4.74	4.89
Fe ₂ O ₃ %	0.63	0.62
SiO ₂ %	3.84	4.93
Al ₂ O ₃ %	0.76	0.95
Pb %	1.96	2.12

2. Mineralogy

Mineralogical examination of the samples showed that celestite was the major constituent with calcite, galena, sphalerite and pyrite in decreasing order of abundance.

Electron probe microanalysis showed that the barium in the samples was present in solid solution in the celestite. No barite was identified (Appendix 1).

Electron probe microanalysis showed that the lead in the flotation concentrate was present as galena, cerussite and lead bearing strontianite. There was a close textural association between the cerussite and lead-bearing strontianite. Galena represented about 20 % of the lead in the sample but 90 % of the galena was present as very fine enclosed or attached grains (Appendix 2).

The mineralogical examination showed that the barium and lead specifications for the celestite concentrate could not be achieved.

3. Flotation

Most of the flotation tests were conducted on Zone 3 ore. The flotation response of the Faulted Zone was examined in selected tests.

Summary - Continued

3.1. Zone 3

3.1.1. Grind and Deslime

1 kg samples of minus 10 mesh ore were stage ground in a rod mill to various sizes ranging from minus 65 mesh to minus 270 mesh. The ground product was pumped through a 25 mm diameter cyclone to remove a minus 10 μ m slime fraction before flotation.

The flotation results have not been conclusive but suggest that a primary grind of minus 100 to minus 200 mesh should reject 10 to 12 wgt. % into the slime fraction. A primary grind of minus 65 mesh would require a regrind for satisfactory liberation and a primary grind of minus 270 mesh produced excessive celestite loss in the desliming stage.

The relationship between grinding size and slime rejection in the cyclone overflow is shown in Table 1.

TABLE NO. 1 - The Relationship between Grinding Size and Slime Rejection

Grind mesh	No. of tests	Cyclone Overflow		
		Weight %	Assays % SrSO ₄	% Dist. SrSO ₄
65	2	7.2	50	5.2
100	10	10.0	53	7.5
150	1	10.8	54	8.4
200	4	11.7	56	9.4
270	1	12.7	59	10.6

Pebble mill grinding did not improve the flotation results.

The deslimed pulp was conditioned with xanthate and floated to recover a sulphide concentrate. The main function of the sulphide float was to remove galena and minor sulphide minerals ahead of celestite flotation; an ancillary function was a desliming stage to improve celestite flotation selectivity.

The sulphide flotation was characterized by a high grade lead rougher concentrate followed by a low grade lead scavenger concentrate. The sulphide flotation tailing assayed 0.15 to 0.20 % Pb as celestite flotation feed.

The sulphide flotation conditions and results are contained in Table 2.

Test No.	Grind mesh	Xanthate		Ro. min	S Ro. Conc.			Celestite Flot Feed					
		Type	g/t		Wgt. %	Assay % Pb	% Dist. Pb	Wgt. %	Assays %		% Dist.		
									SrSO ₄	Pb	SrSO ₄	Pb	
25	100	SEX	20	4	4.4	24	72	87	74	0.35	91	20	
28, 42	100	PAX	15	4	5.3	26	79	86	74	0.28	90	14	
38, 39	100	SEX	30	4	7.5	19	79	82	76	0.26	86	12	
65, 66	200	SEX	30	4	6.5	24	81	82	75	0.24	86	10	
52, 53	100	PAX	40	4	7.5	18	83	81	76	0.16	86	8	
54	100	PAX 404	20 20	4	8.4	17	84	81	76	0.15	85	7	

Summary - Continued

3.1.3. Celestite Flotation

The celestite flotation feed was conditioned with sodium silicate and oxalic acid to depress silicate and carbonate gangue ahead of celestite rougher flotation with Aero 845 or Texin SAM. The rougher concentrate was cleaned four times with depressant and collector additions to each stage.

3.1.3.1. Collectors and Frothers

Texin SAM (sodium alkyl sulphosuccinamide) was a slightly but consistently better collector than Aero 845 under similar test conditions and was used throughout most of the testwork.

Both collectors required a froth extender to maintain celestite flotation through roughing and cleaning. FAl, a low grade tall oil fatty acid, was the extender of choice and produced better results than heavy diesel fuel 904.

Scavenger additions of collector and froth extender were required in each stage of the batch flotation tests for a total collector addition of 400 g/t and a total frother addition of 125 g/t (1 to 1 mixture of FAl and MIBC).

TABLE NO. 3 - Comparison of Collectors SAM and 845

Test No.	Collector	Product	Weight	Assays % SrSO ₄	% Dist. SrSO ₄
16	SAM	SrSO ₄ Cl. Conc.	48.5	94.8	66.0
		SrSO ₄ Ro. Conc.	72.5	79.4	82.6
		S Rougher Conc.	7.6	53.3	5.8
		Slime	13.2	52.9	12.6
		Head (Calc.)	100.0	69.6	100.0
15	845	SrSO ₄ Cl. Conc.	45.9	93.4	61.0
		SrSO ₄ Ro. Conc.	76.0	78.9	85.2
		S Rougher Conc.	5.9	42.4	3.6
		Slime	14.1	54.8	10.9
		Head (Calc.)	100.0	70.4	100.0

Summary - Continued

3.1.3.2. Depressants

Sodium silicate and oxalic acid were used throughout the testwork to depress the silicate and carbonate gangue. Soda ash, quebracho and citric acid showed no advantage in early testwork and were not examined further.

The optimum quantities of sodium silicate and oxalic acid have not been determined but range from 1 to 2 kg/t sodium silicate and 0.5 to 1 kg/t oxalic acid.

The recommended relative quantities are 2 parts of sodium silicate to 1 part of oxalic acid. This ratio produces an almost neutral pH in the flotation pulp and encourages celestite floc formation with the collector.

3.1.3.3. Conditioning

The celestite flotation feed pulp at 33 % solids was conditioned for 3 minutes with sodium silicate, 2 minutes with oxalic acid and 2 minutes with collector before rougher flotation. Doubling the conditioning times did not influence the flotation response. Combining the sodium silicate and oxalic acid in one conditioning stage severely reduced flotation selectivity.

Pulp density was not examined.

3.1.3.4. Regrind

Regrinding reduced flotation selectivity.

The 1st cleaner concentrate from Test 32 was reground in a pebble mill with sodium silicate and oxalic acid. Celestite loss in the subsequent cleaner tailing was considerable.

The 2nd cleaner concentrate from Test 68 was reground in a pebble mill with no depressant additions. Celestite loss in the subsequent cleaner tailings was again considerable.

Neither test improved the SrSO_4 grade of the final cleaner concentrate.

Slime production in the regrind could account for the decrease in selectivity.

Summary - Continued

3.1.3.5. Optimum Batch Test Conditions

Several flotation tests produced celestite concentrates assaying >94 % SrSO₄ at 75 to 80 % recovery in batch flotation.

The test conditions and results are contained in Table 4 and Figure 2.

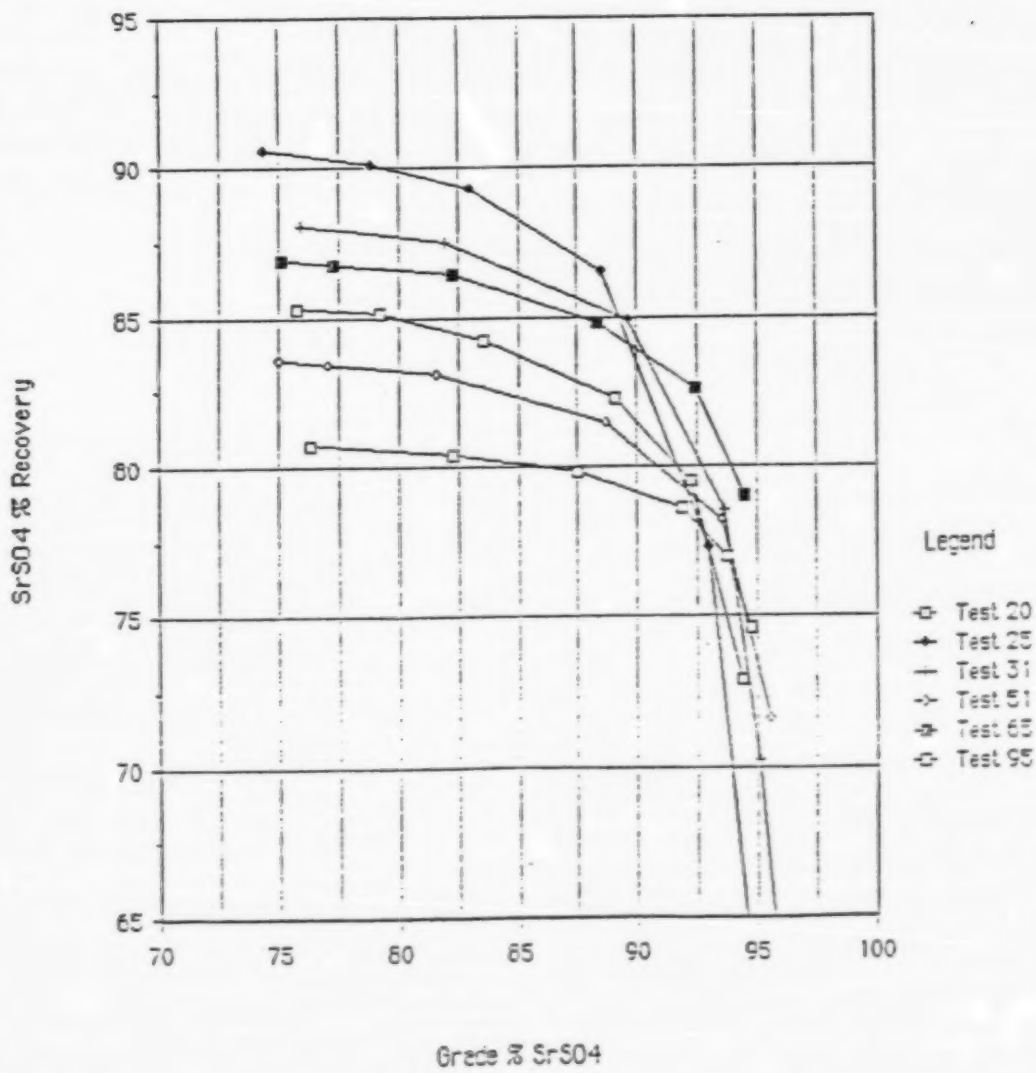
TABLE NO. 4 - Celestite Flotation Conditions and Results

Test No.	Grind Size	Rougher				1st Cleaner				2nd Cleaner				3rd Cleaner				4th Cleaner		Cleaner Conc.		
		NaSil	Oxalic	SAM	FA MIBC	NaSil	Oxalic	SAM	FA MIBC	NaSil	Oxalic	SAM	FA MIBC	NaSil	Oxalic	SAM	FA MIBC	NaSil	Oxalic	Wgt. % SrSO ₄	Assay % SrSO ₄	% Dist. SrSO ₄
20	100 M	800	400	300	75	200	100	50	10	200	100	25	5	150	75	-	-	100	50	54	94.0	75
25	100 M	800	400	300	75	200	100	50	10	200	100	25	5	150	75	-	-	100	50	54	94.0	75
31	100 M	800	400	300	75	200	100	50	10	200	100	50	5	150	75	50	-	100	50	60	93.5	79
95	100 M	1200	600	300	75	300	150	50	15	250	125	25	10	200	100	25	10	150	75	55	94.7	75
51	200 M	1200	600	300	75	300	150	50	10	300	150	25	15	225	115	25	25	150	75	59	93.5	78
65	200 M	1200	600	300	75	300	150	50	10	300	150	25	15	225	115	25	25	150	75	59	94.4	79

*diesel oil 904

Slightly better results were produced at a primary grind of -200 mesh.

FIGURE NO. 2 CELESTITE GRADE vs. RECOVERY



Summary - Continued

3.1.4. Cycle Tests

Two six stage locked cycle tests were conducted with different flowsheets.

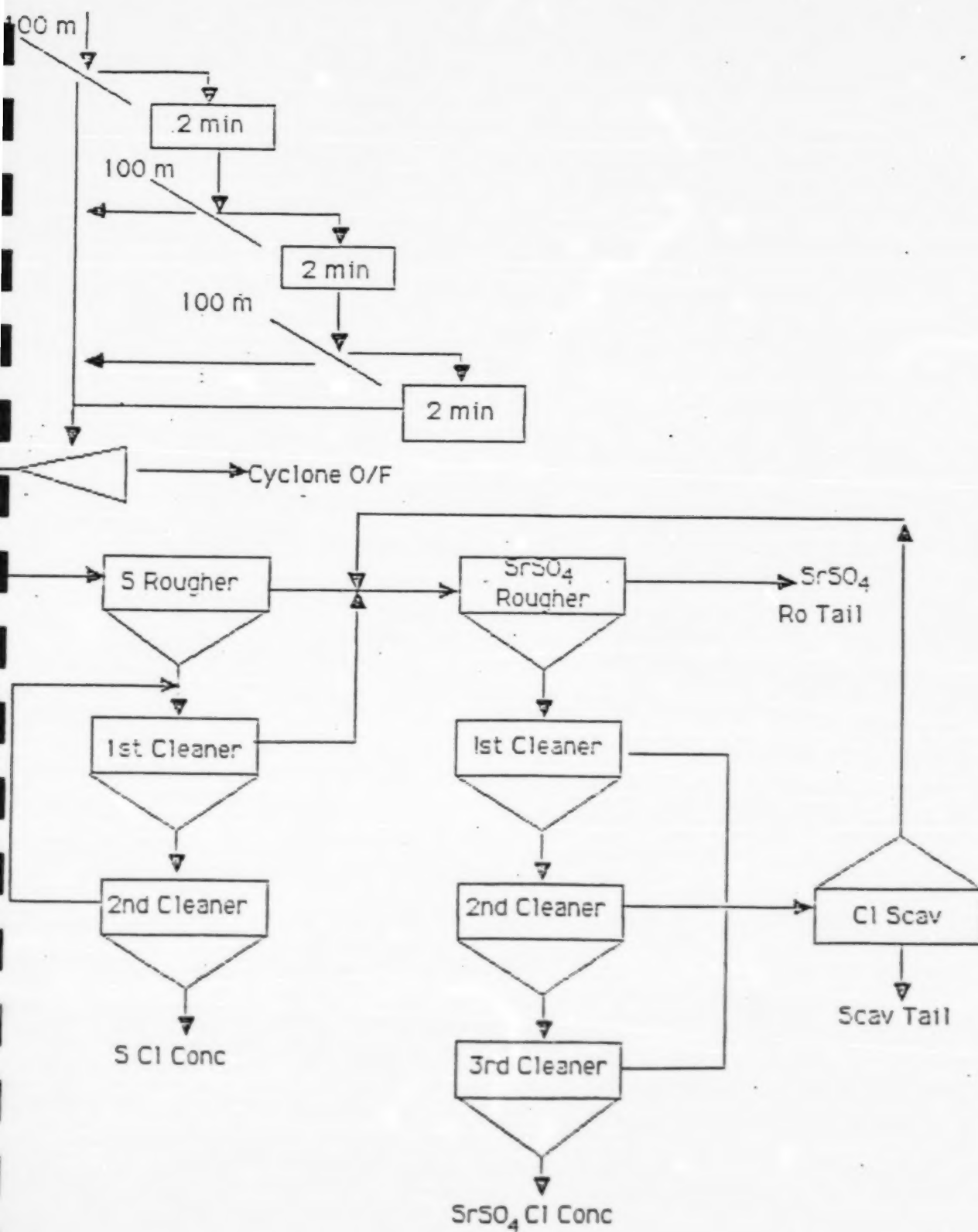
The celestite cleaner tailings were combined and scavenged in Test 43. The scavenger concentrate was combined with the sulphide rougher tailing and the sulphide 1st cleaner tailing as celestite rougher feed. The scavenger tailing was discarded. The flowsheet is illustrated in Figure 3.

Scavenger flotation was not satisfactory. The scavenger tailing assayed 50 % SrSO_4 and represented about 80 % of the celestite loss in the flotation circuit. The results are tabulated below:

TABLE NO. 5 - Cycle Test 43 Results

Product	Weight %	Assays %		% Distribution	
		SrSO_4	Pb	SrSO_4	Pb
SrSO_4 Cleaner Conc.	58.5	90.5	0.23	75.5	7.3
Combined Tail	26.1	39.6	0.43	14.7	6.1
S Cleaner Conc.	4.4	34.2	33.2	2.2	79.3
Cyclone Overflow	11.0	48.7	1.22	7.6	7.3
Head (Calc.)	100.0	70.2	1.84	100.0	100.0

FIGURE NO. 3 - CYCLE TEST 43 FLOWSHEET



Summary - Continued

3.1.4. Cycle Tests - Cont'd

The celestite cleaner tailings in Test 70 were recirculated to the previous cleaning stage in a standard locked cycle configuration as shown in Figure 4.

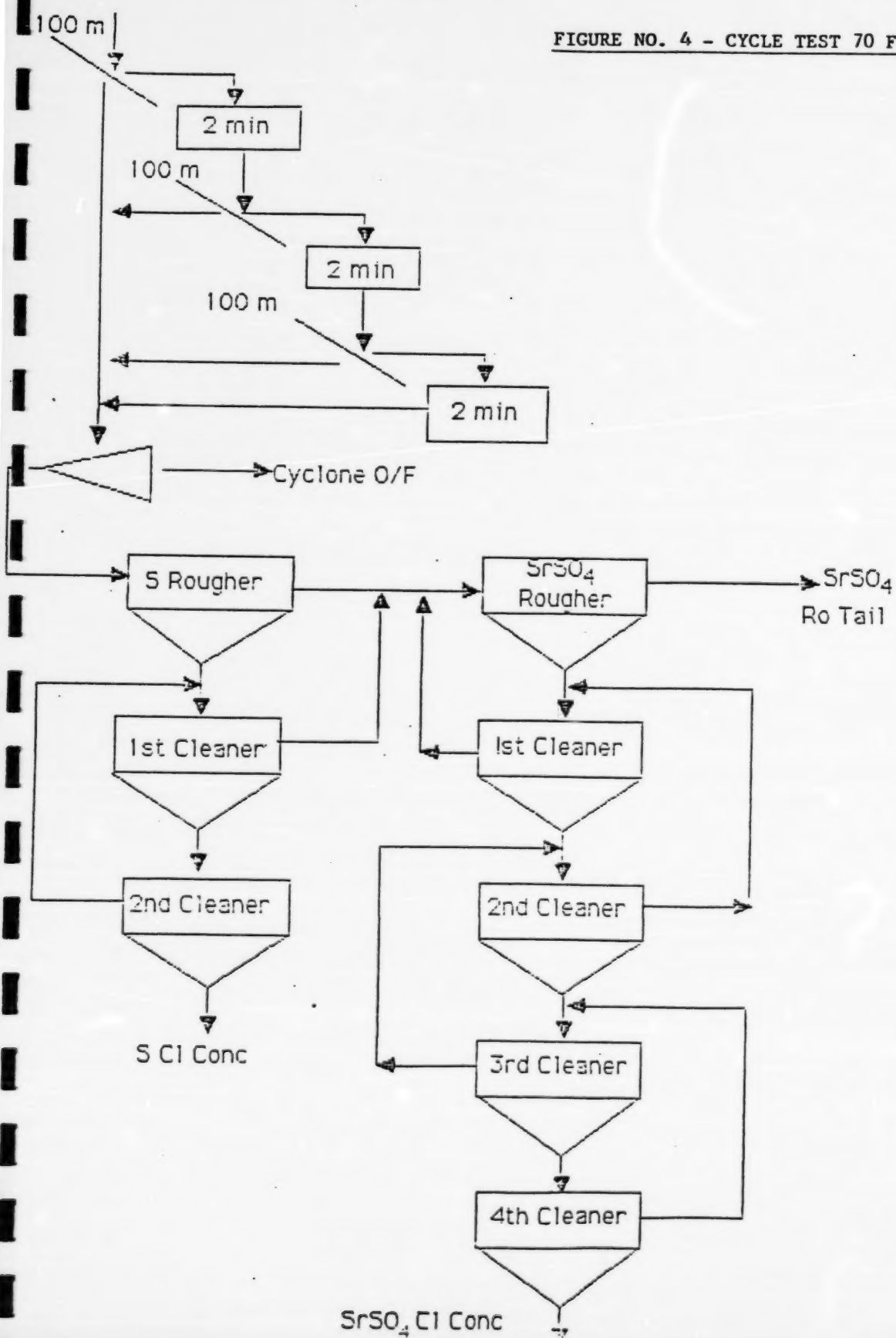
Froth quality deteriorated in the cleaning stages as the test progressed. There was no froth termination point and an arbitrary flotation time had to be selected. The results are tabulated below:

TABLE NO. 6 - Cycle Test 70 Results

Product	Weight %	Assays %		% Distribution	
		SrSO ₄	Pb	SrSO ₄	Pb
SrSO ₄ Cleaner Conc.	64.7	91.3	0.20	83.4	6.9
SrSO ₄ Rougher Tail.	18.8	21.6	0.31	5.7	3.1
S Cleaner Conc.	5.3	41.8	29.3	3.1	82.6
Cyclone Overflow	11.2	48.3	1.23	7.7	7.4
Head (Calc.)	100.0	70.8	1.87	100.0	100.0

For the initial pilot plant flowsheet it is planned to (1) discard the sulphide rougher concentrates; (2) scavenge the celestite 1st cleaner tailing and discard the scavenger tailing and (3) scalp the 2nd, 3rd and 4th cleaner tailings and discard the scalp tailing. The scalp concentrate should be of sufficient grade to combine with the cleaner concentrate as the celestite concentrate. This flowsheet should minimize frothing problems.

FIGURE NO. 4 - CYCLE TEST 70 FLOWSHEET



Summary - Continued

3.2. Faulted Zone

The flotation response of the faulted zone was similar to Zone 3 at the same flotation conditions as shown in Table 7.

TABLE NO. 7 - Comparison of Faulted Zone and Zone 3

Feed	Test No.	Product	Weight %	Assay % SrSO ₄	% Dist. SrSO ₄
Faulted Zone	56	SrSO ₄ Cleaner Conc.	54.2	94.7	71.1
		SrSO ₄ Rougher Conc.	75.3	80.6	84.0
		SrSO ₄ Rougher Tail.	3.9	6.65	0.4
		S Rougher Conc.	9.0	48.7	6.1
		Cyclone Overflow	11.8	58.1	9.5
		Head (Calc.)	100.0	72.2	100.0
Zone 3	68	SrSO ₄ Cleaner Conc.	59.6	92.5	82.0
		SrSO ₄ Rougher Conc.	72.1	78.6	84.2
		SrSO ₄ Rougher Tail.	9.1	4.76	0.6
		S Rougher Conc.	8.4	53.4	6.7
		Cyclone Overflow	10.4	54.7	8.5
		Head (Calc.)	100.0	67.2	100.0

3.3. Solid/Liquid Separation

The thickening and filtration characteristics of a similar celestite concentrate (Beckwith) were excellent. The celestite concentrate settled in six minutes from 35 to 66 % solids for a calculated thickener area of 0.05 m²/t/24 h. Filter requirements were <0.01 m²/t/24 h to produce a filter cake with 8 % moisture.

Summary - Continued

4. Celestite Concentrate

Several celestite concentrates were prepared during the course of the investigation for acid leaching and conversion testwork.

TABLE NO. 8 - Celestite Concentrates

Compound	1	2	3	4
SrSO ₄ %	91.80	93.48	93.69	93.48
BaSO ₄ %	1.22	1.36	-	-
CaCO ₃ %	3.48	1.95	2.21	2.38
MgCO ₃ %	1.36	0.86	0.90	0.92
FeSO ₃ %	0.13	0.11	-	-
Al ₂ O ₃ %	0.095	0.096	-	-
SiO ₂ %	0.54	0.40	-	-
Pb %	0.12	0.15	-	-
Zn %	0.017	-	-	-
Mn %	0.062	-	-	-
Total %	98.82	98.41	-	-

4.1. Celestite Acid Leach

An HCl leach reduced the calcite content of the celestite concentrates to <0.15 % CaCO₃. Recommended leach conditions were 50°C, 66 % solids, at pH <1.5 for 30 minutes. Acid requirements were 1.3 x stoichiometric as shown in Table 9.

Stage grinding the concentrate to -200 mesh did not improve the results.

Summary - Continued

4.1. Celestite Acid Leach - Cont'd

TABLE NO. 9 - Celestite Acid Leach

Test No.	Conc HCl		Time min.	Final pH	Res. Wgt %	Residue Assay %			% Dissolution		
	kg/t	Stoic*				SrSO ₄	CaCO ₃	MgCO ₃	SrSO ₄	CaCO ₃	MgCO ₃
71	64	0.95	30	4.5	95.5	97.2	0.35	0.16	0.2	86	84
72	64	0.95	90	4.7	96.0	96.6	0.48	0.27	0.2	80	72
73	86	1.27	30	2.0	94.5	97.2	0.13	0.02	0.2	95	98
74	86	1.27	90	1.5	95.2	97.5	0.10	0.01	0.3	96	98
86	96	1.42	30	1.1	95.9	96.8	0.10	0.02	0.3	96	98
87	96	1.42	90	1.0	95.9	97.2	0.09	0.01	0.3	97	99
88	106	1.57	30	1.1	95.7	96.8	0.10	0.02	0.3	96	99
89	106	1.57	90	1.0	95.6	96.8	0.08	0.01	0.3	97	99

Leach Conditions: 50°C, 66 % solids, celestite conc 4

*based on 2 mol HCl per mol CaCO₃ and MgCO₃

4.2. Solid/Liquid Separation

The thickening and filtration characteristics of the acid leached celestite concentrate were similar to the flotation concentrate.

The acid leached residue settled in 40 minutes from 65 to 79 % solids for a calculated thickener area of 0.03 m²/t/24 h. Filter requirements were <0.01 m²/t/24 h to produce a filter cake with 8 % moisture (Test 27).

Washing tests on the filter cake in a Buckner funnel showed 94 % washing efficiency with 3 x 2 displacement washes ie, the wash ratio was 2 (Test 86).

5. Strontium Carbonate Production

A hydrometallurgical process was investigated in the production of strontium carbonate from celestite. The process involved three major stages: 1. Conversion of celestite to crude strontium carbonate; 2. Dissolution of the crude strontium carbonate

Summary - Continued

5. Strontium Carbonate Production - Cont'd

in HCl and purification of the strontium chloride solution and 3. Precipitation of strontium carbonate from the strontium chloride solution.

5.1. Conversion

The celestite concentrate was converted to strontium carbonate in a soda ash solution by a process called metathesis:



Several parameters were examined:

1. molar ratio of $\text{Na}_2\text{CO}_3:\text{SrSO}_4 = 1.1:1$ to $1.5:1$
2. temperature 80°C to 120°C
3. time 1 hour to 12 hours
4. solids:solution ratio 1:4, 1:3, 1:2, 1:1.5
5. feed size -100 to -270 mesh

The process was complicated by precipitation of burkeite ($\text{Na}_2\text{SO}_4 \cdot 1/2 \text{Na}_2\text{CO}_3$) at sodium concentrations >130 g/L Na.

The test conditions and results are contained in Tables 10 and 11.

The recommended conversion conditions were : 95°C , 20 % solids (solids:solution = 1:4), 4 hours, 1.1:1 molar ratio of $\text{Na}_2\text{CO}_3:\text{SrSO}_4$ and -270 mesh feed size to produce >97 % conversion efficiency.

Conversion efficiency increased with fineness of grind and temperature. A conversion temperature of 95°C was considerably more efficient than 80°C .

Summary - Continued

5.1. Conversion - Continued

TABLE NO. 10 - Conversion Test Conditions

Test No.	Temp °C	Time h	Mol* Ratio	Density % Solids	Celestite Wgt g	SrSO ₄ Wgt g	Water Vol mL	Na ₂ CO ₃ Wgt g	Na g/L	SO ₄ g/L**	CO ₂ g/L***	Feed Size % -270M
34	80	4	1.5	30	250	234	1000	204	89	122	38	53
35	80	6	1.5	33	500	469	1000	408	177	245	77	53
37	80	6	1.5	40	500	469	750	408	234	324	102	53
59	120	2	1.5	20	250	234	1000	204	89	122	38	53
82	120	2	1.1	20	250	234	1000	149	65	122	8	53
83	120	2	1.5	25	333	312	1000	271	118	163	51	53
60	120	2	1.1	25	333	312	1000	199	86	163	10	53
84	120	2	1.1	33	500	469	1000	299	130	245	15	53
85	80	4	1.5	33	500	469	1000	408	177	245	77	53
97	80	4	1.5	25	333	312	1000	271	118	163	51	53
98	80	4	1.5	25	333	312	1000	271	118	163	51	100
114	95	4	1.1	20	250	234	1000	149	65	122	8	100

*molar ratio Na₂CO₃:SrSO₄

**assuming complete conversion SrSO₄ to SrCO₃

***excess CO₂

TABLE NO. 11 - Conversion Test Results

Test No.	Intermediate Residue				Final Residue				Converted Product							
	Time h	Assays %		Conv. %	Time h	Assays %		Conv. %	Wgt g	Assays %						Moist. %
		Na	S(T)			Na	S(T)			SrCO ₃ *	Na ₂ CO ₃	CaCO ₃	S(T)	S(Sol)	S(T)**	
34	-	-	-	-	4	1.28	0.25	98.7	210	95.0	2.95	0.38	0.25	0.09	-	14
35	-	-	-	-	6	1.40	3.21	82.7	438	92.2	3.23	0.33	3.21	0.48	0.94	15
37	-	-	-	-	6	1.26	5.89	67.5	447	89.3	2.90	0.28	5.89	0.67	1.90	13
59	1	1.60	0.41	97.9	2	0.79	0.17	99.1	213	96.9	1.82	-	0.17	0.05	0.11	14
82	1	0.82	0.92	95.6	2	0.62	0.78	96.3	203	96.4	1.43	-	0.78	0.12	0.15	10
83	1	1.18	0.23	98.9	2	0.91	0.22	98.9	265	97.1	2.10	-	0.22	0.11	0.10	13
60	1	0.77	0.97	95.5	2	0.59	0.90	95.8	263	96.7	1.36	-	0.90	0.14	0.15	13
84	1	1.07	2.04	90.1	2	0.80	1.78	91.4	414	94.9	1.84	-	1.78	0.22	0.18	12
85	2	1.62	5.65	70.9	4	1.16	4.73	75.6	441	-	2.67	-	4.73	0.52	-	12
97	2	1.85	0.94	95.4	4	1.36	0.51	97.5	277	-	2.72	-	0.51	0.32	-	11
98	2	1.63	0.36	98.3	4	1.14	0.25	98.8	275	-	2.50	-	0.25	0.11	-	23
114	2	-	0.56	97.3	4	-	0.31	98.5	208	-	-	-	0.31	-	-	17

*based on 100 % conversion SrSO₄ to SrCO₃

**400 mesh fraction

Summary - Continued

5.1.1. Solid/Liquid Separation

The crude SrCO_3 product was separated from the $\text{Na}_2\text{SO}_4/\text{Na}_2\text{CO}_3$ solution by thickening and filtration. A similar product (Beckwith at 75 % -200 mesh) settled in 3 minutes from 12 to 68 % solids for a calculated thickener area of $0.06 \text{ m}^2/\text{t}/24 \text{ h}$. Filter requirements were not determined.

Washing tests on the filter cake showed 98 % washing efficiency with 3 x 2 displacement washes. The moisture content of the filter cake ranged from 12 % to 23 % depending upon the feed size analysis.

The temperature of the pulp during solid/liquid separation should be maintained above 40°C to prevent the precipitation of burkeite $\text{Na}_2\text{SO}_4 \cdot 1/2 \text{ Na}_2\text{CO}_3$ (see Solubility Tables page 33).

Summary - Continued

5.2. Dissolution and Purification

5.2.1. Dissolution

The crude strontium carbonate was dissolved in a stoichiometric quantity of hydrochloric acid:



A considerable amount of stable froth was produced on the surface of the vessel by the reaction of CO_2 gas bubbles with remaining flotation collector.

Recommended leach conditions were 50°C and 40 % solids to pH <1.5 for 60 minutes. Acid requirements were about 1 kg conc HCl per kg celestite concentrate. The target solution concentration was 350 g/L SrCl_2 .

5.2.2. Purification

The SrCl_2 solution was purified in three stages.

Barium was removed in the first stage with sulphuric acid addition to precipitate BaSO_4 . The sulphuric acid addition was 2 x stoichiometric (2 mols H_2SO_4 /mol Ba) and was added as a dilute solution at 100 g/L H_2SO_4 to improve utilization and reduce SrSO_4 precipitation. The reaction time was maintained at 30 minutes with a solution temperature of 50°C .

Iron was removed in the second stage. A dilute solution of 100 g/L NaOH was added to the solution over a period of 60 minutes to neutralize the solution to pH 7 and precipitate iron hydroxide. The solution temperature was maintained at 50°C to improve the crystallinity of the precipitate and the filtration properties.

Summary - Continued

5.2.2. Purification - Cont'd

Calcium and lead were removed in the third stage with sodium oxalate addition to precipitate CaC_2O_4 and PbC_2O_4 . The sodium oxalate addition was 2 x stoichiometric (2 mols $\text{Na}_2\text{C}_2\text{O}_4$ /mol Ca) and was added as a dilute solution at 100 g/L $\text{Na}_2\text{C}_2\text{O}_4$. The reaction time was maintained at 30 minutes with a solution temperature of 50°C.

The necessity of oxalate precipitation would be determined by the calcium and lead analyses of the neutralized SrCl_2 solution.

The residue/precipitate represented about 8 wgt % of the crude SrCO_3 and removed >95 % of the Al, Si and Fe and >80 % of the Ba in the crude SrCO_3 . Strontium losses were about 8 %.

Strontium losses in the residue/precipitate could probably be reduced to less than 5 % with process development in continuous operation ie, optimization of reagent concentrations, amounts, rates of addition, retention times and temperatures.

5.2.3. Solid/Liquid Separation

The purified SrCl_2 solution was separated from the residue/precipitate by thickening and filtration. A similar residue/precipitate (Beckwith) settled in 1 hour from 2 to 10 % solids for a calculated thickener area of 4 m²/t/24 h. Filter requirements were not determined.

Washing tests on the filter cake showed 99 % washing efficiency with 3 x 2.5 displacement washes, ie the wash ratio was 2.5. The moisture content of the filter cake was 23 %.

The feed solution to precipitation analysed about 300 g/L SrCl_2 .

Summary - Continued

5.3. SrCO_3 Precipitation

Strontium carbonate was precipitated from the strontium chloride solution by reaction with soda ash:



The strontium carbonate product had to meet chemical specifications which could only be realized if the product was relatively crystalline.

Poorly crystallized products were difficult to dewater and wash and were contaminated with occluded and/or soluble impurities, especially sodium.

The conditions that favoured crystallinity were dilute feed solutions, high temperature, slow neutralization, increased concentration of common ion (Cl), and recirculated seed crystals. All these factors were examined in the testwork as shown in Tables 12 and 13.

The best results were achieved in Test 49 at 50°C with 50 % seed recirculation and 4 h neutralization with 100 g/L Na_2CO_3 . The SrCO_3 precipitate analysed 99 % SrCO_3 and 0.28 % Na_2CO_3 . The filtration rate was about 100 kg/m²/h.

TABLE NO. 12 - SrCO_3 Precipitation Test Conditions

Test No.	Temp °C	SrCl ₂		Na ₂ CO ₃			Time h	Seed SrCO ₃		NaCl g	Sr % Pptn
		mL	g/L	mL	g/L	mL/min		g	%		
44	25	1000	100	710	100	3	4	nil	nil	nil	100
45	25	1000	100	710	100	3	4	23.5	25	nil	100
46	25	1000	100	710	100	12	1	23.5	25	nil	100
47	25	1000	100	710	100	1.5	8	23.5	25	nil	100
48	25	1000	100	710	100	3	4	47.0	50	nil	100
49	50	1000	100	710	100	3	4	47.0	50	nil	100
61	50	1000	100	710	100	6	2	nil	nil	nil	100
62	50	1000	100	710	100	6	2	47.0	50	nil	100
63	75	1000	100	710	100	6	2	nil	nil	300	100
64	75	1000	100	710	100	6	2	nil	nil	nil	100
80	75	333	300	710	100	6	2	nil	nil	nil	100
81	75	333	300	237	300	2	2	nil	nil	nil	100
110	50	1000	125	630	100	2.6	4	nil	nil	nil	70
111	50	1000	125	630	100	1.3	8	nil	nil	nil	70
112	50	1000	125	630	100	1.3	8	23.5	25	nil	70
113	50	1000	125	570**	100	2.4	4	nil	nil	nil	50

* % recirculation

** (NH₄)₂CO₃

Summary - Continued

5.3. SrCO_3 Precipitation - Cont'd

TABLE NO. 13 - SrCO_3 Precipitation Test Results

Test No.	Product Wgt.* g	Ppte Wgt. g	Filter Dia. mm	Cake Thick mm	Filter Time min.	Filter Rate kg/m ² /h	Moist %	Precipitate	
								Assay % Na	% Dist. Sr
44	91	91	195	4	13	14	41	0.20	99
45	106	83	195	4	13	16	40	0.12	96
46	115	92	195	4	6	39	48	0.29	99
47	111	88	195	4	5.5	41	45	0.10	99
48	135	88	195	5	9	30	41	0.10	98
49	138	91	195	5	3	92	42	0.10	99
61	93	93	195	5	4	47	48	0.16	99
62	139	92	195	5	5.5	51	43	0.12	99
63	93	93	195	4	4	47	47	0.31	99
64	95	95	195	4	3	64	49	0.24	99
80	93	93	195	4	2.5	75	46	0.27	99
81	89	89	125	7	8.5	51	44	0.32	99
110	81	81	195	4	4	41	46	0.20	70
111	81	81	195	4	4	41	45	0.18	70
112	104	80	195	4	4	53	39	0.30	70
113	49	49	195	3	1.5	66	51	0.12	45

*Precipitate + seed

The crystallinity of the SrCO_3 precipitate was not improved by increasing the concentration of the Cl ion or by precipitating only 50 to 70 % of the available Sr.

5.3.1. Solid/Liquid Separation

The SrCO_3 precipitate was separated from the salt solution by thickening and filtration. Thickener requirements were not determined. Filtration rates (as determined on a Buckner filter) ranged from 50 to 100 kg/h/m² at precipitation temperatures >50°C.

The filter cake was washed with 3 x 1.5 displacement washes, repulped at 20 % solids, filtered and washed with 3 x 1.5 displacement washes. Filter cake moistures ranged from 40 to 50 %.

The washing results indicated that the Na was not present as soluble Na in the free moisture content of the SrCO_3 precipitate, but was occluded within the precipitate. Improved crystallization would be required to reduce the sodium content to <0.15 % Na_2CO_3 .

Summary - Continued

5.3.2. SrCO₃ Analysis

The strontium carbonate precipitate from tests 49 and 61 assayed as follows:

<u>Component</u>	<u>Test 49</u>	<u>Test 61</u>	<u>Spec %</u>
SrCO ₃ (%)	99.0	98.8	>99.0
BaCO ₃ (%)	0.12	0.20	< 1.0
CaCO ₃ (%)	0.60	0.50	< 0.2
MgCO ₃ (%)	0.017	0.015	< 0.2
Na ₂ CO ₃ (%)	0.28	0.37	< 0.15
Fe ₂ O ₃ (%)	<0.01	<0.01	< 0.01
Al ₂ O ₃ (%)	<0.01	<0.01	-
SiO ₂ (%)	<0.1	0.09	-
S (%)	<0.05	<0.05	< 0.04
Pb (%)	0.047	0.017	-
Zn (%)	0.004	0.003	-

The calcium content could be reduced by improved acid leaching of the celestite concentrate or by oxalate precipitation of the neutralized SrCl₂ solution. Oxalate precipitation of the neutralized SrCl₂ solution would also improve Pb rejection.

The sodium specification should be achieved with carefully controlled SrCO₃ precipitation possibly at higher temperatures with more dilute solutions.

Sedigraph analysis of the strontium carbonate precipitates from Tests 49 and 61 were as follows: $K_{95} = 3 \mu\text{m}$, $K_{80} = 2 \mu\text{m}$ and $K_{50} = 1 \mu\text{m}$ (Appendix 3).

RECOMMENDATIONS AND DISCUSSION

Flotation tests on the MacRae Zone 3 ore produced concentrates assaying >94 % SrSO_4 at 75 to 80 % recovery in batch tests on the washed ore. Washing and crushing of the ore was described in Progress Report No. 1, Project No. LR 3155.

Continuous tests should improve celestite recovery. Frothing problems encountered in laboratory locked cycle tests should be minimized with a flowsheet design limiting the recycling of intermediate products.

The main gangue components in the flotation concentrate were calcium and magnesium carbonates which could be leached with hydrochloric acid. The economics of leaching versus flotation should be examined for various concentrate grades.

The celestite concentrate was converted to crude SrCO_3 by reaction with soda ash. The recommended conditions were 95°C, 20 % solids, 4 h, 1.1:1 molar ratio of Na_2CO_3 : SrSO_4 and -270 mesh feed size. It should be noted that the molar ratio of Na_2CO_3 to SrSO_4 could be reduced to 1.03:1 at 95°C, 22 % solids and 12 h reaction time according to Canadian Patent 965576⁽¹⁾. The cost benefit from a reduced molar ratio is worth examining further.

CO_2 produced in HCl dissolution of the crude SrCO_3 could be collected for reuse in the final precipitation stage.

Strontium losses in the purification of the SrCl_2 solution were about 8 % but could probably be reduced to less than 5 % with optimization of reagent concentrations, amounts, rates of addition, retention times and temperatures.

(1) L. Trew, Kaiser Aluminum and Chemical Corp., Purification of Strontium Carbonate, April 8, 1975, Canadian Patent 965578.

Recommendations and Discussion - Continued

SrCO_3 was precipitated from the neutralized SrCl_2 solution by reaction with soda ash. Most of the Pb, Ba and Ca in the SrCl_2 solution were also precipitated by the soda ash and reported in the final product. The relatively high Na analysis of the final product was not expected. Initially it was believed that the Na was present as soluble Na in the free moisture content of the SrCO_3 precipitate. Later washing results indicated that the Na was occluded in or coprecipitated with the SrCO_3 .

The precipitation reaction was extremely rapid and the product had a K_{50} of 1 μm . Consequently it may be quite difficult to reduce the Na analysis of the SrCO_3 precipitate ie, extended reaction times with very dilute solutions.

Effluent treatment was not examined in the test program. There were three main effluent streams (1) $\text{CaCl}_2/\text{MgCl}_2$ solution from HCl leach of celestite concentrate (2) Na_2SO_4 solution from Na_2CO_3 conversion of celestite concentrate and (3) NaCl solution from Na_2CO_3 precipitation of SrCl_2 solution.

Economic viability of the process would require Na_2SO_4 recovery by crystallization and electrolysis of the NaCl solution in a chlor-alkali cell to regenerate HCl and NaOH.

SOLUBILITY TABLES

The water solubility of several salts associated with the investigation are listed below:

Compound	Solubility in Water			
	g/L	°C	g/L	°C
SrSO ₄	0.11	0	0.11	100
SrCO ₃	0.01	20	0.65	100
SrCl ₂	435	0	1008	100
SrCrO ₄	1.2	15	30	100
SrC ₂ O ₄ · H ₂ O	0.051	18	50	100
BaSO ₄	0.002	18	0.003	50
BaCO ₃	0.02	20	0.06	100
BaCl ₂	310	0	590	100
BaCrO ₄	0.003	15	0.004	30
BaC ₂ O ₄	0.093	18	0.228	100
PbSO ₄	0.043	25	0.056	40
PbCl ₂	9.9	20	33.4	100
PbC ₂ O ₄	0.0016	18	-	-
CaSO ₄	2.09	30	1.62	100
CaSO ₄ · 2H ₂ O	2.41	0	2.22	100
CaCO ₃	0.014	25	0.018	75
CaCl ₂	595	0	1590	100
CaCl ₂ · 6H ₂ O	2790	0	5360	20
CaC ₂ O ₄	0.4	25	0.3	50
CaC ₂ O ₄ · H ₂ O	0.007	13	0.014	95
Na ₂ SO ₄	48	0	427	100
Na ₂ SO ₄ · 7H ₂ O	195	0	440	20
Na ₂ SO ₄ · 10H ₂ O	110	0	927	30
Na ₂ CO ₃	71	0	455	100
Na ₂ CO ₃ · 7H ₂ O	169	0	339	35
Na ₂ CO ₃ · 10H ₂ O	215	0	4210	104
NaCl	357	0	391	100

Solubility Tables - Continued

LANGE'S HANDBOOK OF CHEMISTRY (solubility in water g/100 mL)

Compound	Solid Phase	0 °C	10 °C	20 °C	30 °C	40 °C	50 °C	60 °C	70 °C	80 °C	90 °C	100 °C
Na ₂ CO ₃ Na	10H ₂ O	7 3.0	12.5 5.4	21.5 9.3	38.8 16.8							
Na ₂ CO ₃ Na	H ₂ O	- -	- -	- -	50.5 21.9	48.5 21.0	- -	46.4 20.1	- -	45.8 19.9	- -	45.5 19.7
Na ₂ SO ₄ Na	10H ₂ O	5 1.6	9 2.9	19.4 6.3	40.8 13.2	- -	- -	- -	- -	- -	- -	- -
Na ₂ SO ₄ Na	7H ₂ O	19.5 6.3	30 9.7	44 14.3	- -	- -	- -	- -	- -	- -	- -	- -
Na ₂ SO ₄ Na		- -	- -	- -	- -	48.8 15.8	46.7 15.1	45.3 14.7	- -	43.7 14.2	- -	42.5 13.8
Na ₂ SO ₄ . 1/2 Na ₂ CO ₃ * Na		- -	- -	- -	- -	- -	- -	- -	- -	- 13-15**	- -	- -

*Burkeite

**Lakefield Research

SAMPLE PREPARATION

The Zone 3 and Faulted Zone ores were washed and crushed to -3 mesh as described in Project No. LR 3155, Progress Report No. 1.

The 1 tonne -3 mesh samples of each ore were riffled to reject 750 kg to storage. 250 kg were cone crushed to -6 mesh and riffled to reject 125 kg to storage. 125 kg was roll crushed to -10 mesh and riffled into test charges and a head sample for analysis.

SCREEN ANALYSES:

Zone 3 - Minus 10 Mesh - Head

Mesh Size (Tyler)	% Retained		% Passing Cumulative
	Individual	Cumulative	
+ 10	0.2	0.2	99.8
14	10.9	11.1	88.9
20	11.7	22.8	77.2
28	12.8	35.6	64.4
35	10.5	46.1	53.9
48	9.8	55.9	44.1
65	7.7	63.6	36.4
100	6.5	70.1	29.9
150	5.8	75.9	24.1
200	4.8	80.7	19.3
270	3.6	84.3	15.7
400	3.1	87.4	12.6
- 400	12.6	100.0	-
Total	100.0	-	-

Sample Preparation - Continued

Screen Analyses - Cont'd

Faulted Zone - Minus 10 Mesh

Mesh Size (Tyler)	% Retained		% Passing Cumulative
	Individual	Cumulative	
+ 10	0.4	0.4	99.6
14	15.6	16.0	84.0
20	13.0	42.0	58.0
28	13.0	42.0	58.0
35	9.5	51.5	48.5
48	8.4	59.9	40.1
65	6.5	66.4	33.6
100	5.4	71.8	28.2
150	5.0	76.8	23.2
200	4.2	81.0	19.0
270	3.2	84.2	15.8
400	2.8	87.0	13.0
- 400	13.0	100.0	-
Total	100.0	-	-

Section 6

A pilot plant investigation of

THE RECOVERY OF STRONTIUM

from MacRae ore samples

submitted by

CHROMASCO

(A Division of Timminco Ltd.)

Lakefield Project No. LR 3261

Work on this project was conducted under the auspices of
the Department of Energy, Mines and Resources

DSS FILE NUMBER: 03SQ.23440-6-9031
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EMR SCIENTIFIC AUTHORITY: R.K. Collings,
Head, Non-Metallic Minerals Section
Canada Centre for Mineral and
Energy Technology
405 Rochester Street,
Ottawa, Ontario. K1A 0G1.

NOTE:

This report refers to the samples as received.

The practice of this Company in issuing reports of this nature is to require the recipient not to publish the report or any part thereof without the written consent of Lakefield Research.

LAKEFIELD RESEARCH
A Division of Falconbridge Limited
Lakefield, Ontario
March 25, 1987

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ABSTRACT

Pilot plant flotation tests on MacRae celestite ore established the following relationship between celestite grade and recovery.

<u>Assay</u>	<u>% Recovery</u>
<u>% SrSO_4</u>	<u>SrSO_4</u>
70	100
85	85
90	84
92	80
94	65

Analyses of the celestite concentrates showed the following composition at various grades.

SrSO_4 %	94.6	92.0	90.1
Ba SO_4 %	1.39	1.48	1.43
CaCO_3 %	1.87	3.18	4.73
Mg CO_3 %	0.67	1.23	2.01
Fe_2O_3 %	0.12	0.13	0.17
Al_2O_3 %	0.10	0.13	0.17
SiO_2 %	0.35	0.54	0.77
Pb %	0.16	0.17	0.18

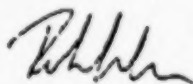
The flotation response of faulted zone ore was similar to Zone 3 ore after washing and desliming.

INTRODUCTION

Pilot plant tests were conducted on MacRae celestite ore to establish the relationship between celestite grade and recovery and to produce celestite concentrates for evaluation by potential consumers.

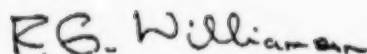
The objectives were outlined in Chromasco P.O. No. H-2720-80 referenced to DSS File No. 03-SQ23440-6-9031.

LAKEFIELD RESEARCH



R.S. Salter

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Experimental Work by: S.J. Parker

SUMMARY

1. General

A total of sixteen pilot plant tests were conducted in this investigation. Zone 3 ore was examined in fifteen tests and a comparative test was conducted on faulted ore.

The basic flowsheet included a rod mill grind followed by cyclone desliming. Sulphides were floated from the sand fraction. Celestite was floated from the sulphide tailing and cleaned several times to produce a celestite concentrate. The flowsheet is illustrated in Figure No. 1.

The objectives of the pilot plant tests were to establish the relationship between celestite grade and recovery and to produce celestite concentrates for evaluation by potential consumers.

Within these broad objectives were the more specific objectives of evaluating various flowsheet configurations and comparing celestite collectors Henkel SAM and Cyanamid 845.

2. Feed

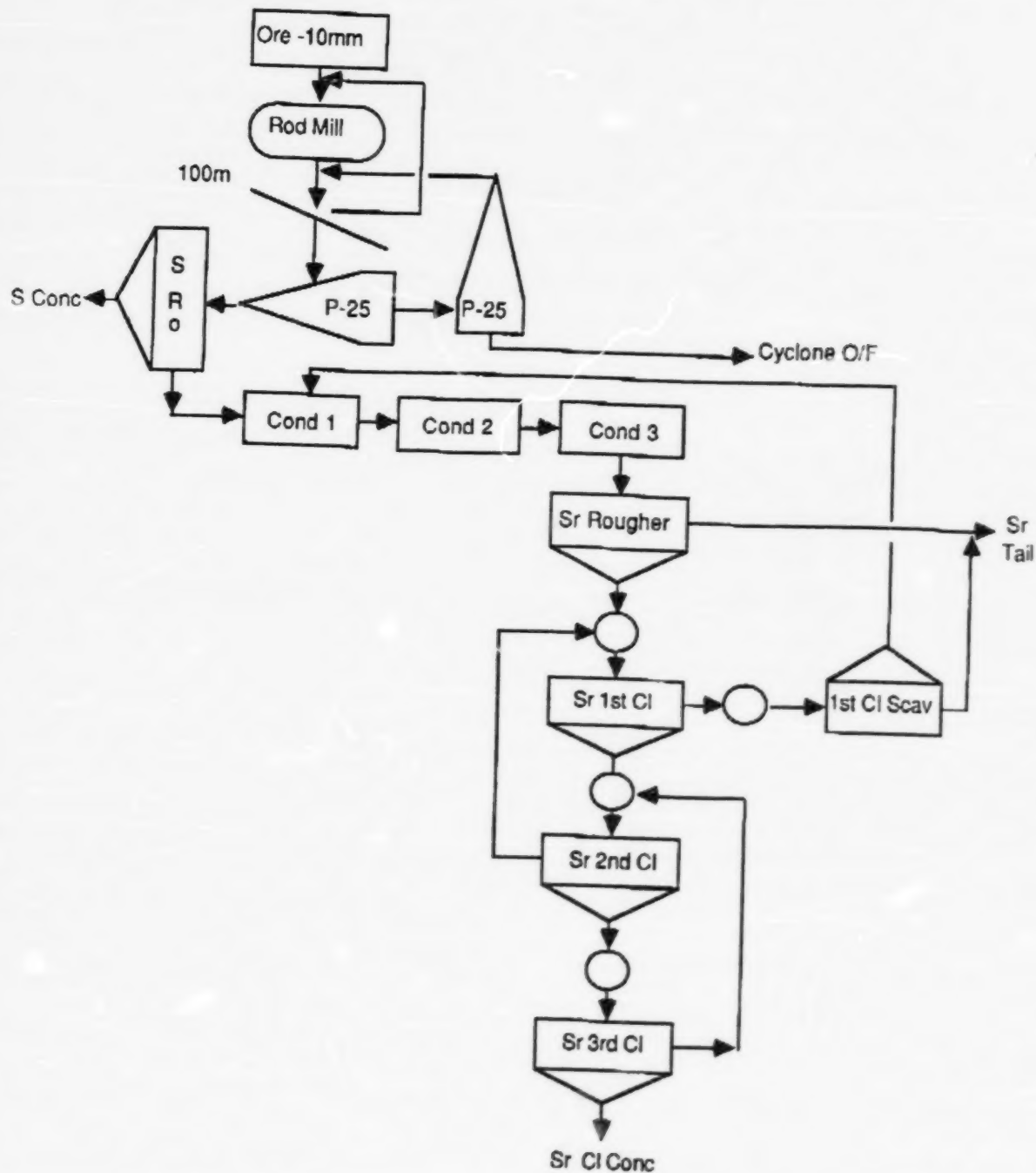
The sample preparation (washing and crushing) of the Zone 3 and faulted zone ores was described in Project No. LR 3155.

Approximate analyses of the washed ores were as follows: 70% SrSO_4 , 1.1% BaSO_4 , 13.5% CaCO_3 , 4.8% MgCO_3 , 0.5% Fe_2O_3 , 4-5% SiO_2 , 0.8% Al_2O_3 and 2% Pb. The faulted zone had a slightly higher silica content.

Electron probe microanalysis showed that the barium was present in solid solution in the celestite. No barite was identified, as described in Project No. LR 3171, Volume 2.

The celestite analysis of the Zone 3 ore feed to the pilot plant tests ranged from 70.7% to 71.8% SrSO_4 and averaged 71.2% SrSO_4 . The celestite analysis of the faulted zone ore was 69.9% SrSO_4 .

FIGURE NO 1: RECOMMENDED FLOWSHEET



Summary - Continued

3. Grinding

The ore was ground at 75 kg/h in a rod mill in closed circuit with a 100 mesh screen. Net power consumption was 6 kWh/t to produce a ground product with a K_{80} of 200 mesh.

4. Desliming

The ground product was deslimed in one or two stages. Single stage desliming rejected 13.3 wgt % and analysed 61.1% SrSO_4 for an average loss of 11.5% SrSO_4 . The cyclone overflow was about 92% $-20\mu\text{m}$.

Two stage desliming reduced the weight loss to 8.5 wgt % and analysed 56.6% SrSO_4 for an average loss of 6.8% SrSO_4 . The cyclone overflow was about 99% $-20\mu\text{m}$.

5. Sulphide Flotation

The deslimed product was conditioned with 50 g/t PAX and floated to remove a galena/pyrite froth product ahead of celestite flotation. The sulphide concentrate represented 4.0 wgt % and analysed 25.4% SrSO_4 for an average loss of 1.6% of the celestite in the feed.

6. Celestite Flotation

The main emphasis in the testwork was to develop an efficient flowsheet with minimum frothing problems. Both collectors Henkel SAM and Cyanamid 845 had frothing properties and it was anticipated that recirculation of intermediate products would cause excessive frothing.

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Summary - Continued

The initial tests were in open circuit. Gradually the circuit was closed as froth control did not appear a major problem. The froth could be controlled with moderate amounts of launder water and water sprays on the conditioning tanks. Henkel SAM produced a more controlled froth than Cyanamid 845.

Three basic circuit configurations were examined, with two to four cleaning stages in each:

- (1) closed circuit flotation
- (2) recirculation of combined tailings to the rougher feed
- (3) scavenging of combined tailings and recirculation of the scavenger concentrate to the rougher feed.

The number of cleaning stages was more important than the circuit configuration.

All three circuit configurations produced celestite concentrates assaying 90 to 92% SrSO_4 at >80% recovery of the celestite in the feed.

Celestite recovery could not be maintained through four cleaning stages and decreased sharply in celestite concentrates assaying >92% SrSO_4 as shown in Figure No. 2.

Reagent requirements were as follows:

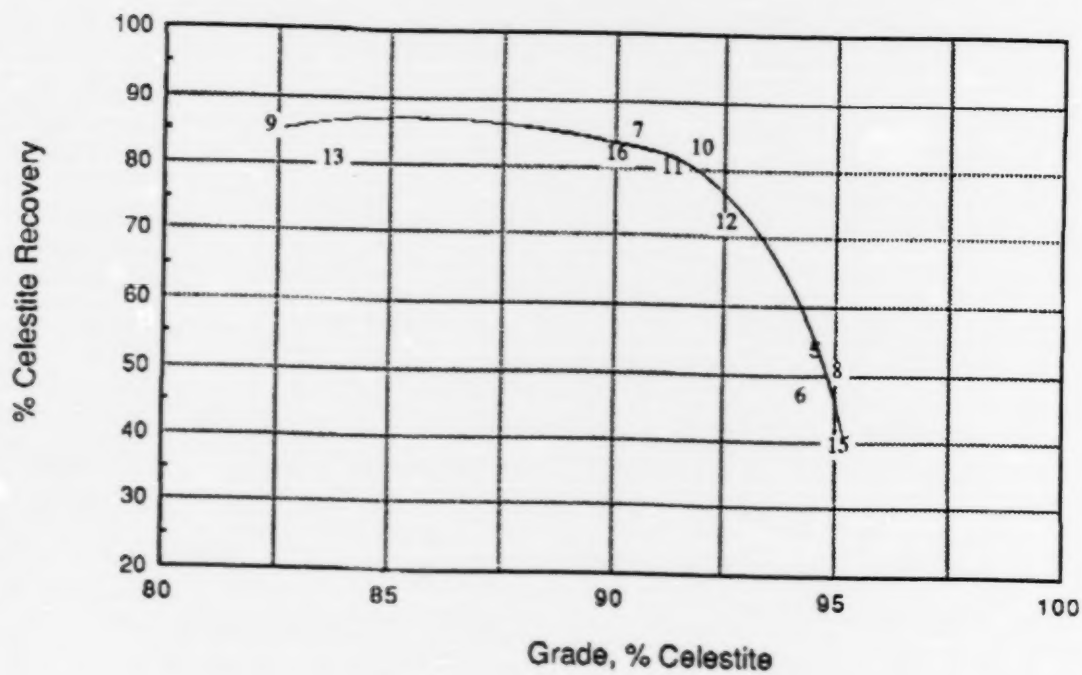
Sodium silicate	1.2 kg/t
Oxalic acid	0.8 kg/t
SAM	400-450 g/t
FA1/MIBC	100-120 g/t

7. Faulted Zone

The grinding, desliming and flotation response of faulted zone ore was similar to Zone 3 ore.

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Fig.No 2 Celestite Grade—Recovery



Summary - Continued

8. Concentrate Analysis

The celestite concentrates were analysed as follows:

Test No.	5, 6, 8*	10*	16**
SrSO ₄ %	94.6	92.0	90.1
BaSO ₄ %	1.39	1.48	1.43
CaCO ₃ %	1.87	3.18	4.73
MgCO ₃ %	0.67	1.23	2.01
Fe ₂ O ₃ %	0.12	0.13	0.17
Al ₂ O ₃ %	0.10	0.13	0.17
SiO ₂ %	0.35	0.54	0.77
Pb %	0.16	0.17	0.18

* Zone 3

** faulted zone

DISCUSSION1. Grinding

The grinding circuit was closed with a 100 mesh screen throughout the test. The ground product had a k_{80} of 200 mesh.

Size fraction analyses of the celestite flotation feed, concentrate and tailing indicated that selectivity not liberation was the controlling factor in the flotation response. A finer grind would increase celestite losses in desliming.

Size Fraction Analyses (Test PP11)

Celestite	Mesh	Weight % O/A	Assay % SrSO ₄	% Distribution O/A
Feed	+ 150 - 150 + 200 - 200 + 400 - 400	5.3 15.6 22.8 40.1	67.1 75.0 63.7 82.4	4.9 16.3 20.3 46.3
	Head	83.8	75.0	87.8
Concentrate	+ 150 - 150 + 200 - 200 + 400 - 400	3.0 11.6 18.1 30.5	93.5 93.2 76.5 99.3	3.9 15.1 19.3 42.4
	Head	63.2	91.4	80.7
Tailing	+ 150 - 150 + 200 - 200 + 400 - 400	2.3 4.0 4.7 9.6	32.7 22.3 14.4 28.9	1.0 1.2 1.0 3.9
	Head	20.6	24.7	7.1

Discussion - Continued

Selectivity indices for the various size fractions were calculated as follows:

Mesh	Selectivity Index *
+ 150	42
- 150 + 200	52
- 200 + 400	27
- 400	62

$$SI^* = \frac{R-C}{100-C} \times \frac{c}{c_{\max}-f} \times 100$$

where C = wgt % of concentrate
 R = % recovery of SrSO_4 in concentrate
 c = SrSO_4 assay of concentrate
 $c_{\max}$ = max. SrSO_4 assay of concentrate
 f = SrSO_4 assay of feed

2. Celestite Flotation

2.1 Collectors

Henkel SAM appeared a superior collector than Cyanamid 845. Low grade concentrates of 82-84% SrSO_4 were produced in Tests PP9 and 14 with Cyanamid 845. More foam developed in the flotation cells with 845 than with SAM.

2.2 Circuit Configuration

Large circulating loads developed with more than three cleaning stages in the flotation circuit unless the first cleaner tailing was scavenged and the scavenger tailing discarded, as shown in recommended flowsheet, Figure No. 1.

2.3 Pulp Density

The rougher pulp density was strongly influenced by the circuit configuration and ranged from 18% solids in Test 7, to 23% solids in Tests 11 and 16, to 33% solids in Test 10.

The density should be increased to 40% solids without adversely affecting flotation performance.

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SUMMARY TABLES

Table No. 1 - Overall Results

Test No.	Cyclone O/F			S Concentrate			Sr Tailing			Sr Concentrate		
	Wgt %	Assay % SrSO ₄	% Dist'n. SrSO ₄	Wgt %	Assay % SrSO ₄	% Dist'n. SrSO ₄	Wgt %	Assay % SrSO ₄	% Dist'n. SrSO ₄	Wgt %	Assay % SrSO ₄	% Dist'n. SrSO ₄
PP2	10.0	61.4	8.6	3.9	25.8	1.4	23.5	68.4	22.9	62.6	75.0	67.0
PP3A	15.4	65.4	14.2	6.8	42.6	4.0	53.4	70.5	51.9	24.5	88.6	29.9
PP3B	15.4	65.4	14.2	6.8	42.6	4.0	15.3	46.4	9.8	62.5	83.5	72.0
PP4	11.2	61.5	9.6	3.0	20.0	0.9	39.6	59.0	32.5	46.2	88.7	57.1
PP5A	18.1	61.2	15.7	3.3	27.2	1.3	40.8	56.3	32.4	37.9	94.9	50.7
PP5B	18.1	61.2	15.7	3.3	27.2	1.3	24.8	33.7	11.8	53.8	93.6	71.2
PP6A	15.3	61.7	13.1	2.8	17.0	0.7	46.7	60.9	39.7	35.3	94.6	46.6
PP6B	15.3	61.7	13.1	2.8	17.0	0.7	28.5	47.5	18.7	53.5	91.3	67.5
PP7	15.7	60.5	13.4	3.2	17.1	0.8	15.5	8.43	1.9	65.6	90.8	83.9
PP8	12.4	61.2	10.7	3.7	16.5	0.9	48.7	61.3	41.9	35.1	94.2	46.6
PP9	14.6	61.0	12.5	3.2	16.0	0.7	8.2	14.2	1.6	74.0	82.3	85.2
PP10	11.7	60.3	9.9	2.5	22.1	0.8	20.5	19.5	5.6	65.2	92.0	83.8
PP11	9.6	59.3	7.9	6.6	46.2	4.3	20.6	24.7	7.1	63.2	91.4	80.7
PP12	7.6	58.6	6.3	4.1	11.8	0.7	32.0	45.6	20.4	56.3	92.4	72.7
PP13	9.6	56.9	7.7	2.8	28.5	1.1	19.0	38.4	10.3	68.7	83.7	81.0
PP14	5.5	53.8	4.2	4.4	27.4	1.7	41.4	62.3	36.3	48.7	84.3	57.8
PP15	10.4	54.6	8.0	6.2	37.9	3.3	52.1	63.8	46.8	31.3	95.0	41.9
PP16	11.2	58.2	9.3	8.0	47.0	5.4	16.4	10.2	2.4	64.4	90.1	82.9

Table No. 2 - Grinding Data

Test No.	Rod Mill		Mill Discharge			Circ. Load %	Ground Product				Power Cons kWh/t	Work Index	Ore
	Feed kg/h	Steel kg	g/L	+65m %	-200m %		Description	-200m %	-30µm %	K ₈₀ µm			
PP4	75.0	165	1988	2.5	64.5	25.4	Screen U/S	81.0	48	72	6.64	6.5	Zone 3
PP5	75.8	165	1985	2.8	67.1	18.2	Screen U/S	78.7	48	75	6.81	6.8	Zone 3
PP6	75.0	165	1985	2.5	66.3	26.1	Screen U/S	82.4	56	70	6.60	6.4	Zone 3
PP7	76.3	125	1979	8.3	41.3	94.8	Screen U/S	78.0	46.3	75	5.80	5.8	Zone 3
PP8	75.0	125	2030	9.0	36.0	118.3	Screen U/S	73.4	44	83	5.88	6.3	Zone 3
PP9	75.0	145	1983	4.8	52.2	52.6	Screen U/S	75.5	54	78	5.78	5.9	Zone 3
PP10	75.0	145	1995	4.1	53.8	84.5	Screen U/S	74.0	44	81	5.83	6.1	Zone 3
PP11	75.0	145	1973	3.7	56.2	25.6	Comb.Cy.*	82.3	49.1	71	5.35	5.2	Zone 3
PP12	75.0	145	1987	3.7	57.5	25.8	Comb.Cy.*	75.8	42.5	81	5.08	5.3	Zone 3
PP13	75.0	165	2007	4.0	56.9	19.3	Comb.Cy.*	78.7	45.1	76	4.75	4.8	Zone 3
PP14	75.0	165	1998	3.4	59.3	35.4	Comb.Cy.*	82.4	51.8	70	4.85	5.6	Zone 3
PP15	75.0	165	2025	1.7	69.6	18.1	Comb.Cy.*	81.1	47.5	71	5.79	5.6	Zone 3
PP16	75.0	165	2012	1.9	70.1	7.8	Comb.Cy.*	83.0	38.2	68	6.34	6.0	Faulted

* Cyclone 1 U/F + Cyclone 2 O/F

Summary Tables - Continued

Table No. 3 - Desliming Data

Test No.	Cyclone Stages	Cyclone O/F				
		Weight %		Cumulative % Passing		
		Assay	Time-Wgt	30 μ m	20 μ m	10 μ m
PP2	1	10.0	-	98	94	74
PP3	1	15.4	18.8	88	77	55
PP4	1	11.2	-	99	95	74
PP5	1	18.1	8.2	98	94	78
PP6	1	15.3	11.3	96	90	75
PP7	1	15.7	-	96	91	74
PP8	1	12.4	16.8	95	90	72
PP9	1	14.6	16.3	97	92	77
PP10	1	11.7	15.5	97	93	79
PP11	2	-	9.6	-	99	93
PP12	2	-	7.6	-	99	92
PP13	2	-	9.6	-	99	90
PP14	2	-	5.5	-	98	82
PP15	2	-	10.4	-	99	95
PP16	2	-	11.2	-	99	93

Summary Tables - Continued

Table No. 4 - Circuit Configuration

Test No.	Cleaning Stages	Flowsheet
PP3B	2	Open circuit.
PP4	3	Scalp 2nd and 3rd cleaner tailing. No recycle.
PP5A	4	Scalp 3rd and 4th cleaner tailing. No recycle.
PP5B ⁺	4	Recycle 3rd and 4th cleaner tailing to rougher feed.
PP6 ⁺	4	Recycle 2nd to 4th cleaner tailing to rougher feed.
PP7 ^o	2	Scavenge combined rougher and cleaner tailings. Recycle scavenger concentrate to rougher feed.
PP8 [*]	4	Closed circuit except scavenge 1st cleaner tailing. Recycle scavenger concentrate to rougher feed.
PP9 [*]	2	Closed circuit.
PP10 ^o	3	Scavenge combined rougher and cleaner tailings. Recycle scavenger concentrate to rougher feed.
PP11 ⁺	3	Recycle 1st to 3rd cleaner tailing to rougher feed.
PP12 ^o	4	Scavenge combined rougher and cleaner tailings. Recycle scavenger concentrate to rougher feed.
PP13 [*]	3	Closed circuit.
PP14 ^o	3	Scavenge cleaner tailings. Recycle scavenger concentrate to rougher feed.
PP15 [*]	4	Closed circuit.
PP16 [*]	3	Closed circuit.

⁺ recycle tailings to rougher feed

^o scavenge tailings and recycle scavenger concentrate to rougher feed

^{*} closed circuit

Summary Tables - Continued

Table No. 5 - Reagent Additions

Test No.	Ore	Collector Type	NaSil Type	Rougher Additions				Total Additions			
				NaSil kg/t	Oxalic kg/t	Collector g/t	FA/MIBC g/t	NaSil kg/t	Oxalic kg/t	Collector g/t	FA/MIBC g/t
PP3	Zone 3	SAM	Metso	0.6	0.9	260	40	1.2	1.3	260	40
PP4	Zone 3	SAM	N	1.0	0.8	420	115	1.7	1.1	420	115
PP5A	Zone 3	SAM	O	1.2	0.8	320	70	2.0	1.2	410	90
PP5B	Zone 3	SAM	O	1.2	0.8	310	70	2.0	1.2	310	70
PP6	Zone 3	SAM	O	1.2	0.8	310	70	1.8	1.2	330	90
PP7	Zone 3	SAM	O	0.6	0.4	300	70	1.1	1.1	450	120
PP8	Zone 3	SAM	O	0.6	0.4	310	70	0.9	0.6	380	110
PP9	Zone 3	845	O	0.8	0.6	310	90	1.0	0.7	310	90
PP10	Zone 3	SAM	O	0.6	0.4	310	70	1.2	0.7	410	95
PP11	Zone 3	SAM	O	0.6	0.4	320	90	1.2	0.7	400	120
PP12	Zone 3	SAM	O	0.7	0.4	250	50	1.4	1.2	350	90
PP13	Zone 3	SAM	O	1.3	0.8	360	70	1.9	1.1	460	110
PP14	Zone 3	845	O	0.6	0.4	280	70	1.2	0.7	480	130
PP15	Zone 3	SAM	O	0.6	0.5	360	90	0.9	0.6	440	140
PP16	Faulted	SAM	O	0.8	0.6	360	90	1.2	0.8	360	90

Table No. 6 - Pulp Densities (g/L)

Test No.	R.M. Disch.	Cyclone 1			Cyclone 2		Sr	Sr	Sr	Sr	Sr	Sr
		Feed	U/F	O/F	U/F	O/F	Ro. Feed	Ro/Scav Tail	Comb. Tail	1st Cl. Feed	2nd Cl. Feed	3rd Cl. Feed
PP2	2030	1250	1405	1090	-	-	1158	1067	1058	-	-	-
PP3A	2042	1237	1430	1087	-	-	1560	-	1060	1100	1070	1080
PP3B	1988	1245	1415	1108	-	-	1460	-	1070	1250	1130	1140
PP4	1998	1135	1328	1058	-	-	1300	-	1072	1097	1170	1150
PP5A	1985	1159	1222	1027	-	-	1243	1025	1060	1117	1112	1138
PP5B	1982	1190	1300	1035	-	-	1250	-	1060	1105	1095	1130
PP6	1985	1139	1281	1045	-	-	1191	1058	1083	1267	-	-
PP7	1979	1134	1335	1045	-	-	1110	1045	-	1060	1113	-
PP8	2030	1133	1316	1066	-	-	1360	1060	1085	1238	1310	1220
PP9	1983	1131	1311	1055	-	-	1117	1053	-	1073	1145	-
PP10	1995	1130	1318	1045	-	-	1340	1055	-	1080	1103	1218
PP11	1973	1178	1346	1071	1063	1042	1195	-	-	1190	1250	1300
PP12	1978	1167	1341	1070	1062	1032	1455	1070	-	1143	-	1313
PP13	2007	1187	1398	1080	1055	1038	1245	1045	-	-	-	-
PP14	1998	1273	1329	1131	1045	1025	1298	1068	-	1425	1325	1285
PP15	2025	1107	1295	1042	1045	1030	1300	1080	-	1400	1308	1210
PP16	2012	1157	1312	1050	1050	1030	1200	1050	-	1075	1065	1105

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ORE SAMPLE PREPARATION

1. Sample Receipt

On May 29, 1986 two rail cars were received at Lakefield containing 70 tonnes MacRae Zone 3 and 21 tonnes MacRae faulted zone celestite ores.

2. Feed Preparation

The ore samples were washed and crushed to -7 mm as described in Project No. LR 3155, dated July 22, 1986.

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INVENTORY**1. Ore**

Approximately 60 tonnes of -7 mm MacRae Zone 3 and 20 tonnes of -7 mm MacRae faulted zone remain on hand at Lakefield.

The pilot plant test consumed 600 kg of the 1 tonne representative sample of -7 mm faulted zone ore.

2. Celestite Concentrate

The celestite concentrates from Tests PP5, 6 and 8 were combined, filtered and dried. The net weight was 400 kg. The celestite concentrate from Test PP7 was also filtered and dried. The dried weight was 200 kg.

The celestite concentrates from tests PP9 to 16 were stored as pulps in plastic lined drums.

The analyses of the dried concentrates was as follows:

Test No.	5, 6, 8	7
SrSO ₄ %	94.6	92.6
BaSO ₄ %	1.39	1.38
CaCO ₃ %	1.87	2.95
MgCO ₃ %	0.67	1.09
Fe ₂ O ₃ %	0.12	0.14
Al ₂ O ₃ %	0.10	0.13
SiO ₂ %	0.35	0.54
Pb %	0.16	0.19

SAMPLING

1. Grinding and Flotation Circuits

The grinding and flotation circuits were operated for 3 to 5 hours to obtain equilibrium conditions before samples were removed for analysis.

2. Assay Samples

Composite samples of grinding and flotation circuit products were taken at regular intervals (usually every one-half hour) during the sample period. The sampling was conducted with individual sample cutters of approximately 400 milliliters capacity, with a 12 mm by 150 mm opening. The pulp stream was cut several times at right angles to obtain representative samples. The samples were accumulated for the duration of the sample period, and were then filtered and dried.

Several of the flotation circuit products were sampled with 250 mL or 400 mL capacity plastic cups. The entire pulp stream was collected to provide a specific volume. The samples were accumulated for the duration of the sample period and were then filtered and dried.

3. Pulp Density Samples

Pulp density samples were taken every 30 minutes in the grinding circuit and every hour in the flotation circuit. A direct-reading Marcy pulp balance equipped with a one liter sample container was employed for these tests. The pulp densities were recorded in grams per liter of pulp.

4. Time Weight Samples

A composite sample of the cyclone O/F product was collected for 3 to 5 minutes, filtered, dried and weighed.

REAGENTS**1. Description**

Name	Manufacturer	Description
Aero 350 Texin SAM Porocoll SAM Aero 845 FA1	Cyanamid Henkel Chemicals Henkel Chemicals Cyanamid Arizona Chemical	potassium amyl xanthate alkyl sulphosuccinamate alkyl sulphosuccinamate modified sulphonate tall oil fatty acid
MIBC O Sodium Silicate Oxalic Acid	Shell Chemical National Silicates Nymoc	50% oleic, 42% linoleic, 4% rosin methyl isobutyl carbinol 3.22 SiO ₂ : 1.0 Na ₂ O wgt ratio technical grade

2. Preparation and Application

The reagents were added to the circuit as 1 to 100 % solutions (as noted in the test details) through dropper bottles. The FA1 and MIBC mixture was a 1:1 wgt ratio.

METALLURGICAL CALCULATIONS

1. Two Product Formula

The two product formula was used to calculate the desliming circuit and sulphide flotation.

2. Bllco

Material balance program developed by BRGM.

DESCRIPTION OF EQUIPMENT

1. Washing and Crushing

As described in Project No. LR 3155, Progress Report No. 1.

2. Grinding

2.1 Rod Mill

The Denver rod mill was a low discharge overflow mill with a diameter of 405 mm and a length of 815 mm. The mill was equipped with wave liners and was driven by a 2.2 Kilowatt electric motor through sheaves, V-belts, pinion and bull gears.

2.1.1 Rod Mill Feeding

The feed rate to the rod mill was controlled through a Syntron Model GFM-TO1-8 'weigh-flow' gravimetric feeder.

2.1.2 Power Calculations

The total power was measured by a Sangamo Kilowatt-hour meter, equipped with a rate meter and a cumulative meter. A nominal efficiency of 95 percent was assumed for the power transmission. The no-load power was calculated in the same manner, but with the mill operating empty. Net power was equal to gross power minus the no load power.

2.1.3 Rod Charge

The steel charge was prepared from mild steel rods ranging from 10 mm to 30 mm.

Description of Equipment - Continued

3. Classification

3.1 Screen

A 1.22 m diameter Kason vibrating screen equipped with a 100 mesh screen was used to classify the rod mill discharge.

3.2 Cyclone

P25 Dorrclone cyclones were used to classify the screen undersize in one or two stages. The cyclone internal diameter was 25 mm.

4. Flotation Cells

Denver and Agitair flotation cells had the following capacities.

Denver 4 cell No. 7, DR, 28 L/cell.

Denver 4 cell No. 7, Sub A, 28 L/cell.

Denver No. 7, Sub A, 28 L/cell.

Denver No. 5, Sub A, 7 L/cell.

Agitair 2 cell No. 8, 6.4 L/cell.

5. Conditioners

20 L Denver conditioners were used to condition the rougher feed pulp and the 1st cleaner feed pulp with sodium silicate and oxalic acid.

13 L Lakefield conditioners with Cafrano mixers were used to condition the 2nd to 4th cleaner feed pulp.

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Description of Equipment - Continued

6. Pumps

Denver and Sala sand pumps were used as transfer pumps throughout the circuit.

Section 7

**PRE-FEASIBILITY STUDY
ON THE MacRAE CELESTITE ORE DEPOSIT**

FINAL REPORT

BY

**PHILLIPS BARRATT KAISER
ENGINEERING LTD.**

A.C.A. HOWE INTERNATIONAL LTD.

Work on this project was conducted under the auspices of the Department of
Energy, Mines and Resources

DSS FILE NUMBER: 03SQ.23440-6-9031

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EMR SCIENTIFIC AUTHORITY: R.K. COLLINGS

**Head, Non-Metallic Minerals Section
Canada Centre for Minerals and Energy
Technology**

CHROMASCO

A DIVISION OF TIMMINCO LIMITED

PRE-FEASIBILITY STUDY

ON THE MacRAE CELESTITE ORE DEPOSIT

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1.0 INTRODUCTION

This pre-feasibility study on the MacRae Celestite Ore Deposit in the Loch Lomond area of Cape Breton, Nova Scotia was carried out under the auspices of the Department of Energy, Mines and Resources (DSS Contract 23440-6-9031/01-SQ).

The purpose of the report is to provide an estimate of the ore reserves, develop a mine plan, evaluate the existing concentrator at Lake Enon and review process alternates for the conversion of celestite to glass grade strontium carbonate at Point Edward in Sydney, Nova Scotia.

A.C.A. Howe International Ltd. conducted the evaluation of the reserves, mine plan and mining cost. Phillips Barratt Kaiser Engineering Ltd. completed the work for the concentrator, process plant and economic evaluation.

Capital and operating cost estimates were developed for mining, concentrator and process plant. An economic evaluation on the viability of the project was carried out including sensitivity analysis.

2.0 SUMMARY AND CONCLUSIONS

2.1 Summary

The MacRae Celestite Property hosts a celestite (SrSO_4) deposit which was delineated and partially exploited by Kaiser Celestite Mining Ltd. and Kaiser Aluminum and Chemical Corporation during the 1970's. The mine and concentrator were developed and constructed at Lake Enon in the Loch Lomond area and a conversion facility was built at Point Edward in Sydney. Chromasco acquired the exploration rights to the property in 1985 by means of a special licence issued by the Nova Scotia Department of Mines and Energy. Subsequent to the licence, Chromasco signed a contract with the Department of Supply and Services to evaluate the property. Under the terms of the contract and auspices of Energy, Mines and Resources, Chromasco was obligated to carry out four work phases consisting of:

- Phase 1 - Summary of all known celestite properties in Canada and the research and development completed to date with the major emphasis on Lake Enon.
- Phase 2 - Conduct batch test work on concentration and conversion to produce specification strontium sulphate and strontium carbonate.
- Phase 3 - Pilot plant test work on concentration and conversion to produce specification strontium sulphate and strontium carbonate.

Phase 4 - Pre-feasibility study for the commercial operation including mining, concentration and conversion.

All phases are complete and Chromasco contracted the services of Lakefield Research to engage in the concentration and conversion test work; J.B. McCrea, metallurgist to oversee the Lakefield Research work; Phillips Barratt Kaiser Engineering Ltd. to provide flowsheets for concentration and conversion plants, capital and operating costs, tailings disposal, pre-production start-up costs and economics; and A.C.A. Howe International Ltd. to do ore reserve calculations, mine design, and mine capital and operating costs.

The ore reserves and mining plan are based on existing drill hole data from Kaiser Aluminum and Chemical Corporation, original developers of the ore body. Based on this data, the total geological, in-place reserve estimate is 397,500 tonnes of 55.73% SrSO_4 and total mineable reserves are 395,500 tonnes of 53.1% SrSO_4 .

Mining will be conventional open pit by front end loaders and trucks and at a mining rate of 35,000 tonnes per year (10,000 tonnes of SrCO_3 equivalent), the mine would have a life of eleven years.

For the production of strontium carbonate, the basis of the study was the evaluation and costing of the concentrator and developing flowsheets, sizing and costing for the conversion plant located at Point Edward in the Sydney area.

The cases considered for conversion are:

- White Ash process as practiced by Kaiser Aluminum and Chemical Corporation at the original facility at Point Edward (Case 1A).

- White Ash process as above except utilizing locally available salt to produce the required reagents (Case 1B).
- Black Ash process as practiced by the current producers of strontium carbonate.

The information for the study was developed from in-house data, private communication and testwork by Lakefield Research.

Porter Dillon Limited of Halifax were retained to aid in the evaluation of the environmental aspects of the project and to obtain opinions and input from nearby residents and the three levels of government. The overall reaction is favourable, provided that the facilities are designed to meet the mining, environmental and other regulations and all normal licensing and public information procedures are met. For the study, a new tailings system at the concentrator is included along with provisions for collection of surface run-off from the site. These systems effectively isolate the original tailings ponds. The provincial government has indicated that it would prefer that the old ponds be used in any new venture.

Capital and operating costs for the concentrator and processing facilities were developed based on preliminary flowsheets, in-house data and budget quotations from suppliers.

2.2 Conclusions

1. Calculated ore reserves, based on previous data, are sufficient to support a conversion facility to produce 10,000 tonnes per year of strontium carbonate for eleven years.
2. The potential exists for at least tripling the ore reserves with further exploration drilling.
3. All environmental constraints can be met.
4. The existing concentrator can be re-furbished and made operational without major modifications.
5. The "Black Ash" process is the most economical for the production of strontium carbonate.

3.0 PROJECT DEVELOPMENT

The results of this study indicate that the project is viable and if the decision is made to develop it further, the following events would take place.

- o Evaluation of the pre-feasibility study
- o Marketing study, in-fill drilling and decision to proceed with a detailed feasibility study on the selected process
- o Conduct sampling, laboratory and pilot plant work and equipment testing
- o Prepare environmental permits
- o Prepare feasibility study
- o Arrange financing
- o Decision to proceed with engineering and construction

An overall schedule is dependent on many things but a suggested sequence of milestone dates could be as follows:

Pre-feasibility study complete	- April 15, 1987
In-fill drilling	- June 1, 1987
Marketing study	- May 1, 1987
Decision to proceed with feasibility study	- September 1, 1987

- | | |
|---|--------------------|
| Pilot work, equipment tests and feasibility study complete | - December 1, 1987 |
| Study review, financing and partnership discussions and decision to proceed | - July 1, 1988 |
| Environmental permitting, purchase of concentrator and start engineering | - November 1, 1988 |
| Construction start | - April 1, 1989 |
| Mine start-up | - July 1, 1989 |
| Concentrator start-up | - October 1, 1989 |
| Process plant start-up | - March 1, 1990 |

To complete a feasibility study, additional drilling is required to confirm the existing Kaiser data and to define more ore reserves. A more detailed study would be completed on the mine plan in an attempt to reduce the cost of mining for such a relatively low tonnage. Sampling for metallurgical and process testwork would be based on the additional data to ensure a closer match as possible to the final plant feed.

The environmental permitting process would start with the base line evaluation upon the decision to proceed with the study. This would continue throughout the study and the remainder of the project schedule till these and the other permits were obtained. It would be expected that the financing would continue in a like manner.